Sources and Risks of Potential Future Contamination 4

Most research and data collection efforts to date have focused on past radioactive contamination and releases. Beyond the contamination that already exists, however, lies the further risk that future releases, dumping, or accidents could significantly add to this problem. While past dumping and releases have received recent attention from scientists and governments, the risk of future releases has not been subject to the same scrutiny or study.

The following discussion is a review of the nature and general magnitude of this future risk and of what we know or don't know about actions that have been, could be, or should be taken. The discussion is not quantitative because the data that have been collected so far are limited. It is, however, illustrative of several areas of potential future contamination. Even though the potential for significant contamination may be problematic, the risks are real, and in many cases, the proverbial ounce of prevention could well be worth pounds of cure.

According to information currently available, certain areas are at risk of future contamination from Russian nuclear activities in the Arctic and North Pacific regions. OTA has selected three of these areas for focus and analysis in this study because they appear to be the most significant at this time. These are: 1) the Russian Northern and Pacific Fleets and their vulnerabilities during the downsizing and dismantlement now under way; 2) the management of spent nuclear fuel and waste from these fleets and concerns about effective containment safety, security, or future releases; and 3) concerns about possible future accidents or releases from Russian civilian nuclear power plants, particularly those located in the Arctic.

Based on the limited data currently available, it appears important to evaluate appropriate measures for the prevention of future releases, dumping, or accidents like those that have occurred in the past. For example, the situation with regard to the management of spent fuel and other radioactive waste from the Russian nuclear fleet presents a special concern. There are serious problems in Russia related to: submarine dismantlement and the removal of spent fuel from submarine reactors; the storage of spent fuel aboard service ships that are used in the submarine defueling process; spent fuel handling and storage at naval bases in the north and Far East;[1] the lack of capacity at land-based storage facili-

[1] The northern naval bases are mainly on the Kola Peninsula, near the Norwegian border and adjacent to the Barents Sea; the Far Eastern bases are mainly near Vladivostok on the Sea of Japan and Kamchatka.

ties; the question of what to do with damaged fuel and nonstandard fuel for which no reprocessing system exists; the transport of spent fuel; and the system to transfer spent fuel to, and reprocess it at Mayak in the Ural Mountains.

Within the Russian Navy, older nuclear submarines have been retired and decommissioned over the past several years at an increasing rate. Over 120 submarines have been taken out of service, and about 100 nuclear submarines are in various stages of decommissioning. Only about 40 of these have had their spent fuel removed, and some decommissioned submarines have been out of service with nuclear fuel aboard for over 15 years. The most serious factor contributing to this condition is that almost all spent fuel storage facilities at the nuclear fleet bases are full, and there are difficulties in transporting fuel to reprocessing sites.

The Office of Technology Assessment (OTA) has begun to identify some high-priority problems associated with the management of spent fuel from the Russian nuclear fleet through discussions with Russian officials and experts. These problems were reviewed at a special OTA workshop on this subject in Washington, D.C., in January 1995, where Russian officials presented their analysis of the problem and discussed approaches to solutions with technical counterparts from the United States.[2] Some key problems with refueling and storage relate to the current backlog of spent fuel and decommissioned submarines awaiting defueling. There is a lack of fuel reloading and storage equipment (including service ships, transfer bases, and land-based storage), and what does exist is poorly maintained.

In recent years, the Russians have not been able to transport spent fuel to the normal reprocessing plant at Mayak, and spent fuel storage facilities are near capacity. This has become a serious problem for fuel management operations in the Navy and at the Murmansk Shipping Company (MSC) and could affect ship operations in the future. For example, there are indications that GOSATOMNADZOR (GAN), the Russian nuclear regulatory agency, plans to demand submarine defueling as a first step in decommissioning. This may further delay the processing of decommissioning submarines.

In addition, the Russians are experiencing problems with the current situation that result in long-term, in-core fuel storage aboard retired submarines. In some cases, reactor cores and other reactor components of retired submarines are close to or beyond their useful lifetimes. GAN characterizes the technical condition of these systems as "intolerable." Under such circumstances, extended in-core storage of spent fuel may increase the incidence of fuel failure due to radiation or thermal damage to the cladding and to cladding corrosion. According to GAN, these problems often cannot be observed or controlled because of the lack of reactor monitoring equipment. However, the Ministry of Atomic Energy (MINATOM) and the Navy claim that fuel that has not been damaged during reactor operations is unlikely to fail during in-core storage.[3] They also claim that there is even some advantage of in-core storage: after three to five years of storage, fuel can be placed directly in dry storage or sent to Mayak for reprocessing. However, some fuel is already damaged, and no complete analysis of this overall problem is available.

Another key problem is with transportation of spent fuel because of a shortage of railcars for upgraded transportation casks,[4] facilities for loading and transporting the casks, organizational problems at fuel transfer bases, and lack of upgrades in the transportation infrastructure. This problem has recently received attention at the Northern Icebreaker Fleet base at Murmansk,

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[2] See "Summary of Workshop on Russian Naval Spent Nuclear Fuel and Waste Management," U.S. Congress, Office of Technology Assessment, Environment Program (April 1995).

[3] This view is supported by experiments: for example, spent fuel has been kept without deterioration in-core on the icebreaker Sibir' for three years (53).

[4] The Russians have recently introduced a redesigned transportation cask to meet international safety standards.

and several spent fuel shipments have occurred in 1995. The situation in the Far East, however, remains serious, and no shipments appear possible in the short term.

Nonstandard or damaged fuel rods from submarine and icebreaker reactors present another set of problems. Such fuel includes zirconium-uranium alloy fuel, fuel from liquid metal reactors, damaged and failed fuel assemblies, and fuel in damaged reactor cores. Russia does not have current technology to reprocess or dispose of nonstandard or damaged fuel. Also, removing damaged fuel from reactors for temporary storage, and selecting or developing appropriate future treatment or storage technologies, are both challenging and costly. This process is proceeding at a very slow rate because of a lack of resources. Additional evaluation of specific situations and some focused research or development are probably needed to ensure future safe management. The question of future risks from operations to dismantle nuclear submarines and manage spent fuel has recently been addressed in a North Atlantic Treaty Organization (NATO) study (49). Box 4-1 presents analyses of the hypothetical accidents used in this study.

Institutional issues are exacerbating difficulties in the spent fuel management system, as is the problem of identifying the necessary resources to apply to solutions. However, other areas may also pose future risks, but they have not been as well documented or evaluated. For example, the major Russian nuclear test site at Novaya Zemlya contains significant residuals of past weapons testing. During 1955 through 1990, the former Soviet Union (fSU) conducted at least 90 atmospheric tests there (including the largest-yield explosion ever); 42 underground tests (most of which were in tunnels into mountains), and three underwater tests (62). Although there is clear evidence of radiation fallout from atmospheric tests spread over major portions of the globe, the migration of radionuclides from underground tests has not been documented. Some researchers, however, recommend that surveys or monitoring at the test sites may be warranted.

Other sources of radioactivity that have caused concern because they may add to future releases include a large number of so-called peaceful nuclear explosions in Russia that were used for various purposes such as excavation and construction over a period of a several decades. Whether radionuclide residuals from these migrate beyond local sites is problematic, and no careful investigations have been made. Another concern is the extensive use of radioisotope-powered generators by the Russians in a large number of lighthouses in the Arctic. Poor operational, safety, and waste disposal practices could lead to releases from these devises, but no significant threats have so far been identified (49).

The following sections, therefore, present currently available information and analyses of the areas on which OTA has focused its evaluation.

THE RUSSIAN NUCLEAR FLEET

The Russian fleet of nuclear-powered submarines and surface ships (including icebreakers) is the largest in the world, with a total of 140 active vessels at the end of 1994. During the 1970s and 1980s, the size of the Russian nuclear fleet was substantially larger than that of the United States. However, today, the U.S. nuclear fleet—with about 117 vessels—is only slightly smaller. Only three other nations have nuclear fleets—the United Kingdom with 16 submarines, France with 11, and China with one (36). Both the United States and the former Soviet Union began building nuclear-powered submarines in the 1950s and had roughly the same number by the 1970s. In the 1970s and 1980s the Soviet nuclear fleet grew faster and larger than that of the United States. Soviet nuclear fleet strength peaked in 1989, just before the dissolution of the U.S.S.R.

Today's Russian nuclear fleet consists of about 128 active nuclear-powered submarines, five icebreakers, and six other surface ships. An equal or larger number of nuclear-powered ships make up the inactive fleet and are in various stages of lay-up or decommissioning. Much of the inactive fleet consists of submarines awaiting

BOX 4-1: Case Study: Risk Assessment of Moored Submarines

A recent study by the North Atlantic Treaty Organization (NATO) includes two risk assessments that evaluate the impact of hypothetical accidents related to decommissioned Russian nuclear submarines moored in the vicinity of the Kola Peninsula. The first assessment used probabilistic methods to evaluate the risk and long-term impact of radionuclide leakage from 60 nuclear submarines that would have been laid up at Northern Fleet bases located on the Kola Fjord. The model included various exposure pathways such as inhalation, external radiation, and food consumption. Due to the lack of operational data from the Russian Navy, a somewhat arbitrary accident probability of .001 per year per ship was assumed. This probability is equal to the accident probability of the least safe land-based commercial European nuclear power reactors. This hypothetical accident would be initiated by large-scale atmospheric emissions caused by cooling system failure followed by overheating of the core, or perhaps by criticality occurring during defueling of the reactor. The study concluded that in northeastern Scandinavia, the risk of additional fatalities from nuclear reactor accidents in moored nuclear submarines is comparable to those due to the operation of land-based commercial nuclear reactors used for electrical production. In southern Scandinavia, the risk of cancer-related casualties would be 100 times lower from submarine-based accidents than the risk due to nuclear reactors used for electrical production. However, the Russian population exposure in Murmansk and elsewhere on the Kola Peninsula would be higher due to submarine-related accidents.

The second study consisted of a simulation of a real accident at an exact location near the city of Murmansk on the Kola Peninsula. The probabilistic model described above provides useful information regarding mortality risks; however, the risk of injury from a real accident would be significantly higher. This study used historical weather data to predict air mass dispersion patterns. The scenario used in the simulation considered the consequences of an accidental release of radionuclides into the atmosphere from a nuclear submarine being serviced at docks just outside Murmansk. The release was arbitrarily chosen to occur on July 15, 1994. The resulting air dispersion model predicted the formation of a radiation cloud and deposition matrix that would cause both external and inhaled radionuclide exposure. During the first 48 hours, only individuals in the immediate Murmansk area would be exposed to effective radiation doses at milliSievert levels. After that, the radiation cloud would drift north into the Barents Sea. However, two days later the weather patterns might shift, and contaminated air masses would be transported south again across major parts of Finland and northwestern Russia. The authors of the study were careful to note that uncertainties in real-time modeling would lead to a factor of uncertainty of five to 10 times the reported values.

The study concludes that risks associated with the operation of nuclear vessels in Russia's Northern Fleet and icebreakers are difficult to estimate. Accidents that lead to large releases of radioactivity would clearly have significant local consequences, but their cross-border, international impacts would be modest. However, NATO's analysis of the present rate of submarine decommissioning and of the Northern Fleet's capacity for defueling, storing, and transporting nuclear waste indicates that a problem of "considerable magnitude" exists locally in northwest Russia.

SOURCE: North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, *Cross-Border Environmental Problems Emanating from Defense-Related Installations and Activities*, Final Report, Volume I: Radioactive Contamination, Phase I: 1993–1995, (Kjeller, Norway: NATO, 1995).

dismantlement and disposal of their nuclear fuel, reactor compartments, and nuclear waste. The nuclear fuel or waste from poorly managed, laid-up ships could pose a threat to the Arctic or North Pacific environment if accidents or releases of radioactivity occurred.

The total number of nuclear submarines taken out of service is similarly being driven by the

Russian government's policies aimed at reducing the size of the Russian Navy. The actual pace of nuclear submarine decommissioning is, however, subject to speculation and the anticipated impact of the (yet to-be-ratified) START (Strategic Arms Reduction Treaty) II. Bottlenecks in spent fuel and radioactive waste management have slowed down the pace of retirement.

Location and Condition of the Russian Nuclear Fleet

Although some naval units of the fSU have come under the control of former Soviet Republics other than Russia, the two major fleets and the entire nuclear Navy (in the north on the Kola Peninsula and on the Pacific Coast) are wholly Russian. In addition, Russia operates the world's largest fleet of civilian nuclear-powered icebreakers. These ships are operated by the Murmansk Shipping Company and based at its Atomflot facility on the Kola Peninsula. These icebreakers have always been an important component of the Soviet fleet because of the need to operate during winter months.

The Russian Navy is organized into four fleets: the Northern, Pacific, Baltic, and Black Sea Fleets. Like the U.S. Navy, each fleet is further subdivided into strategic and nonstrategic elements. The ballistic missile submarine force (SSBNs) represents the strategic fleet elements. There are no nuclear-powered submarines in service in the Baltic or Black Sea Fleet. Thus, with the breakup of the former Soviet Union, all nuclear-powered submarines and ships remain under Russian Navy command.

The nuclear-powered ships are divided between the Northern Fleet headquartered in Severomorsk on the Kola Peninsula in northwestern Russia near the Norwegian border and the Pacific Fleet headquartered in Vladivostok. Traditionally, submarine forces have been allocated two-thirds to the Northern Fleet and one-third to the Pacific Fleet (36).

Table 4-1 summarizes the types and fleet command of active Russian nuclear vessels as of January 1995. OTA estimates that as of early 1995, a total of 128 nuclear-powered submarines were in active service, 88 in the Northern Fleet and 40 in the Pacific Fleet. In addition, a total of 121 submarines from the Northern (70) and Pacific (51) Fleets have been decommissioned, laid up, or sunk (see table 4-5). A few of these decommissioned submarines are in shipyards for

TABLE 4-1: Russian Nuclear Fleet as of January 1995

Nuclear ships			Northern Fleet/MSC	Pacific Fleet
Ship class and type		Total	Active	Active
SSBN	Ballistic missile submarines	48	32	16
SSGN	Guided missile submarines	22	14	8
SSN/ SSAN	Torpedo attack submarines	58	42	16
CGN	Nuclear cruisers	3	2	1
AGBN	Nuclear icebreakers	7	7	0
AGN	Auxiliary transport	1	1	0
AGBM	Auxiliary missile range	1	0	1
	Total	**140**	**98**	**42**

KEY: MSC = Murmansk Shipping Company

SOURCES: *Jane's Fighting Ships, 1994–95*, Captain Richard Sharpe (ed.), 97th edition (Surrey, U.K.: Jane's Information Group, 1994) ; J. Handler, "Working Paper on: The Future of the Russian Nuclear-Powered Submarine Force," (Draft), Greenpeace Disarmament Campaign, May 15, 1995; T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); V.A. Danilian, Russian Federation Pacific Fleet, Information presented at the Office of Technology Assessment Workshop on Spent Nuclear Fuel and Waste Management, Washington, DC, Jan. 17–18, 1995.

overhaul and upgrade, but the vast majority are tied up at dockside waiting for defueling and dismantlement.

Both the United States and Russia are currently engaged in major efforts to reduce their nuclear arsenals and the size of their military forces. These efforts are driven by agreements or treaties, budget constraints, obsolescence, and general reduction of Cold War justifications for military forces. Many naval nuclear ships of both countries have been retired or inactivated on a regular basis for more than a decade, and this activity will probably continue for more than a decade in the future. Ships are inactivated when they reach the end of their useful lifetime, when policies are implemented to reduce forces, or when such reduction is necessary to comply with treaty requirements that limit ballistic missile capacity. START I and II have provisions calling for reduction in nuclear warhead launchers over specific time periods. START I came into force in December 1994; START II, which was signed in January 1993, has yet to be ratified by either the United States or Russia. These treaties, however, specify a limit only on the number of deployable nuclear weapons—thus, they would require the destruction of launch tubes, but not the dismantlement of submarines or any other actions on nuclear-powered vessels. Some analysts, however, have projected probable actions by the Russian Navy to comply with START I (and START II when it is ratified), as well as actions that will result from general demilitarization and budget reductions in Russia in the future.

Table 4-2 contains a simplified forecast of the Russian nuclear fleet from 1994 to 2003. The data presented in this table are based on various sources (2,12,29,36,48). The data indicate that significant deactivation of nuclear submarines (which has been under way since 1991) will continue in the near future and that another 70 to 80 additional ships or submarines will be added to the current retired fleet (to be dismantled) over the next decade.

The relatively rapid decommissioning of nuclear submarines in the recent past has placed

TABLE 4-2: Projections of Russian Nuclear Fleet Composition and Numbers of Vessels, 1994 through 2003 (Based on an Interpretation of Actions Following Treaty Agreements)

Year	Ballistic missile submarines	Cruise missile submarines	Attack/ auxiliary submarines	Cruisers	Icebreakers	Other	Total nuclear fleet	Cumulative retirements
1990	61	46	74	3	7	2	193[a]	39
1994	48	22	58	3	7	2	140[b]	102[c]
2000	21	14	45	3	8	1	92[d]	157[e]
2003	18	13	26	3	8	1	69[f]	180[g]

[a] See G. Baham, "Nuclear Fleet of the fSU: A Preliminary Analysis of Dismantlement Activities," Staff Paper prepared for OTA, February 1995.

[b] Submarine numbers were obtained from J. Handler, "Working Paper on: The Future of the Russian Nuclear-Powered Submarine Force," (Draft), Greenpeace Disarmament Campaign, May 15, 1995. Remaining data were obtained from *Jane's Fighting Ships, 1994–95*, Captain Richard Sharpe (ed.), 97th edition (Surrey, U.K.: Jane's Information Group, 1994).

[c] This figure includes 101 nuclear submarines and one icebreaker; it does not include 20 nuclear submarines that are in "active service" but laid up and planned for decommissioning.

[d] This figure includes 26 Victor III-class SSNs and 14 Oscar-class SSGNs in the total, some of which may be retired by this date. In addition, three SSN class nuclear-powered submarines which are under construction are included in this total. For more information, see J. Handler, "Working Paper on: The Future of the Russian Nuclear-Powered Submarine Force" (Draft), Greenpeace Disarmament Campaign, May 15, 1995.

[e] This figure includes 154 nuclear submarines, one icebreaker, one cruiser, and one auxiliary.

[f] This projected total assumes a 20-year service life and includes 5 Typhoon and 13 Delta class SSBNs. Also 8 Victor III class SSNs and 13 Oscar class SSGNs were included in the total count, some of which may be retired by this date. In addition, new construction of five SSN class nuclear-powered submarines is included.

[g] This figure includes 177 nuclear submarines, one cruiser, one auxiliary, and one nuclear icebreaker.

SOURCE: Office of Technology Assessment, 1995.

considerable demands on the logistical infrastructure of the Russian Navy. Two factors complicating decommissioning are the simultaneous retirement of a large number of older, first- and second-generation, general-purpose, nuclear-powered submarines. The normal lifetime of these submarines is 20 years according to a Russian Navy source (11). The second factor is the deterioration of economic conditions since the breakup of the Soviet Union. The severely restricted budgets of the past several years have taken a toll on the logistical infrastructure of the Navy.

The Russian Navy operates ten nuclear submarine bases on the Kola Peninsula and five on the Pacific Coast, which provide home ports for its fleet. The maintenance support for these bases is provided by an network of shipyards and repair facilities. The bases provide routine provisioning of consumable items and minor repair services while the submarine is between at-sea deployments. In addition, the critical role of repair facilities and submarine tenders is to keep the nuclear reactor fully serviced, as well as performing repairs on defective systems. These tasks include removal of irradiated liquid and solid waste, as well as replacement of spent nuclear fuel with fresh fuel. Fuel removal is the riskiest part of nuclear submarine maintenance. Spent nuclear fuel represents the majority of radioactivity in the reactor core. In the U.S. Navy, removal of fuel is normally performed in a naval shipyard during dry-docking. The Russian Navy, however, refuels submarines while afloat using service ships equipped for specialized maintenance procedures.

Russia's Northern Fleet

At the end of 1994, the Northern Fleet had 88 nuclear submarines consisting of 32 SSBNs, and 56 SSGN/SSN[5] general-purpose vessels assigned to the Northern Fleet. A total of 70 nuclear submarines have been retired, including three that were sunk. The locations of major Northern Fleet submarine bases are described in box 4-2. Nuclear-powered submarines and surface ships are stationed at nine major bases located from the Norwegian border on the Barents Sea to Gremikha on the east end of the Kola Peninsula in the vicinity of Murmansk (48). Three bases—at Zapadnaya Litsa, Sevmorput, and the shipyard at Severodvinsk—are connected by rail. All others, except Gremikha, have road connections. The maps in figure 4-1 illustrate the general location of Russian nuclear facilities in the regions of Murmansk and Arkhangel'sk.

Nuclear submarine repair and waste storage facilities are located in the same region. The Northern Fleet is served by the shipyards at Severodvinsk, as well as a number of dedicated naval facilities. Radioactive waste is stored at six Northern Fleet locations on the Kola Peninsula (48). The base at Zapadnaya Litsa generates more waste than all the other bases on the Kola Peninsula. These shipyards and other Northern Fleet facilities are discussed in box 4-3.

Two shipyards in the north are engaged in decommissioning Russian nuclear submarines—*Nerpa*, along the Kola Fjord leading to Murmansk; and *Zvezdochka*, at Severodvinsk in Arkhangel'sk Oblast.

Russia's Pacific Fleet

There were 16 SSBNs and 24 SSGN/SSN general-purpose nuclear submarines assigned to the Pacific Fleet at the end of 1994. A total of 51 nuclear submarines have been retired. Some of the "active" assignments are not fully operational, but they have not been officially decommissioned either (29). Traditionally, the Soviet Navy kept about one-third of its nuclear-powered fleet in the Far East. The headquarters of the Pacific Fleet is located in Vladivostok on the Sea of Japan. Figure 4-2, a map of the Russian Pacific Coast, illustrates the location of major naval facilities.

[5] SSBN (Nuclear Ballistic Missile Submarine); SSGN (Nuclear Guided Missile Submarine); and SSN (Nuclear Attack Submarine). See table 4-1 for additional definitions for nuclear-powered ships and submarines.

BOX 4-2: Bases Serving the Northern Fleet of the Russian Navy

Zapadnaya Litsa: This fjord contains the oldest submarine operating facility in the former Soviet Union, also called Murmansk-150, probably commissioned in 1958. Four additional facilities are located along this 16-km-long and 1- to 2-km-wide body of water, including those at Nerpichya Bay, Bolshaya Lopatka Bay, Malaya Lopatka Bay (repair facility), and Andreeva Bay (waste storage). The Russian Navy's six Typhoon SSBNs are based at Nerpichya Bay. Bolshaya Lopatka services general-purpose, guided missile and attack nuclear submarines. Malaya Lopatka is a repair facility, and the Andreeva Bay Base stores nuclear waste materials.

Ara Bay: This is a 10-km fjord about 48 km north-northwest of Murmansk and 16 km east of Zapadnaya Litsa on the Barents Sea coast. The bay contains a small general-purpose nuclear submarine base.

Ura Bay: Ura Bay contains a complex of three facilities for servicing nuclear submarines. Ura Bay is the largest, with two smaller facilities at Chan Ruchey and Vidyaevo.

Sayda Bay: The naval base at Gadzievo is located on the eastern side of Sayda Bay facing the town. Strategic missile submarines are stationed at this facility. Laid-up nuclear submarines are kept at three piers south of the town on the opposite side of the bay.

Olenya Bay: The naval base at Olenya Bay (Murmansk-60) is a small fjord, 6-km-long, located 3 to 4 km south of Sayda Bay and ending at Kut Bay.

Pala Bay: Pala Bay is a small, 4-km-long fjord that juts to the southwest at the entrance to Olenya Bay. The town of Polyarny is located to the east, on the Murmansk Fjord. Delta and Yankee class submarines have been stationed here in the past. Several decommissioned submarines are stored here.

Severomorsk: Severomorsk is the headquarters of the Russian Northern Fleet. It is located on the eastern side of Kola Fjord, 25 km north of the City of Murmansk. Severomorsk is a city of 70,000 in the greater metropolitan area of Murmansk, which has 600,000 inhabitants. The base is also one of the major storage facilities for armaments for the Northern Fleet.

Gremikha: Gremikha, also known as "Yokanga base," is located at the eastern end of the Kola Peninsula on the Barents Sea, 300 km east of the mouth of Kola Fjord. This base has no road or rail access and must be reached by sea. The Alfa class SSNs were based here, before they were laid up, the Oscar class has also been based here.

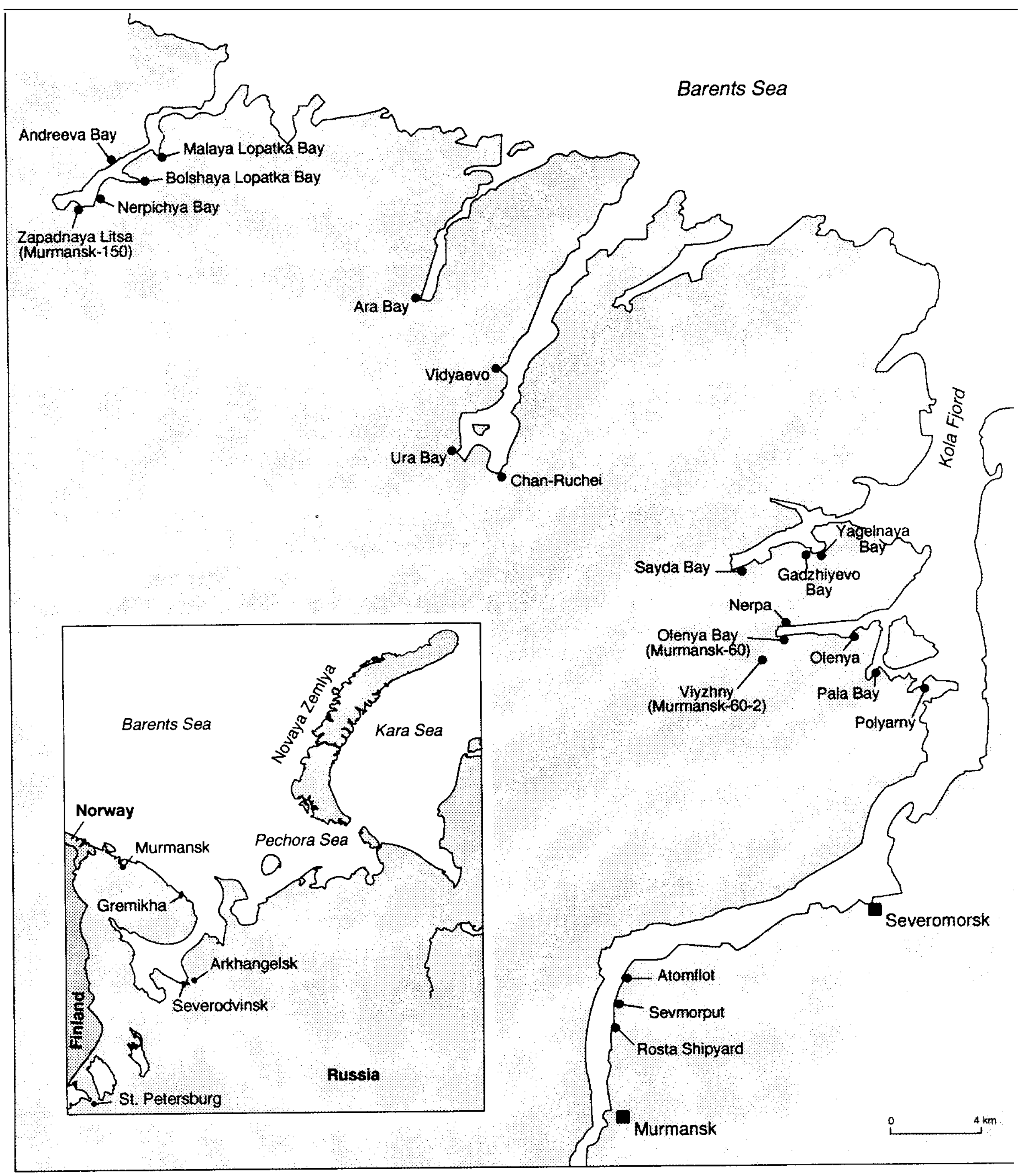
SOURCE: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); J. Handler, "The Northern Fleet's Nuclear Submarine Bases," *Jane's Intelligence Review-Europe*, Dec. 1993.

The location of major bases for submarine operations in the Pacific Fleet is described in box 4-4. Nuclear-powered submarines and surface ships have been stationed at four major bases (Rybachiy, Vladimir Bay, Zavety Ilyicha, and Pavlovsk), and several minor bases from the Kamchatka Peninsula to Vladivostok on the Sea of Japan, near the Chinese border (31). Pacific fleet shipyards and other facilities are shown in box 4-5.

Murmansk Shipping Company Facilities

The operations of the Murmansk Shipping Company (MSC), a private company and operator of the Russian nuclear-powered icebreaker fleet, are conducted out of the Atomflot facility, which is located north of the city of Murmansk. The base is situated on the Murmansk Fjord, which has waterborne access to the Barents Sea via the Kola Fjord. Atomflot is a self-contained facility for supporting the operations of the icebreaker fleet. It contains workshops, liquid and solid waste processing systems, and warehouses for resupply of the ships. Major machinery and hull repairs are performed at dry docks in the City of Murmansk. Zvezdochka shipyard at Severodvinsk makes major repairs to icebreaker reactors.

FIGURE 4-1: Northern Fleet Nuclear Submarine Bases



Source: Office of Technology Assessment, 1995, adapted from Handler, J., "The Northern Fleet's Nuclear Submarine Bases," *Jane's Intelligence Review-Europe,* **Dec. 1993.**

BOX 4-3: Northern Fleet Shipyards, Repair, Refueling, and Nuclear Waste Storage Facilities

Zapadnaya Litsa[a]: Radioactive waste is stored here in containers placed in a concrete bunker. Reported past practices were to cover bunker sections in concrete and seal them as they were filled up.

Olenya Bay: The Nerpa,[a,b] refit yard is located in the town of Olenya Bay. This base has been designated for dismantlement under START I. A small nuclear waste storage facility is located on the southern end of Kut Bay on the beach of the yard.

Pala Bay: Shkval Repair Yard[a] is connected to the Polyarny base at Pala Bay. It is a large repair and refit facility located at the end of the bay for SSN attack class submarines. A naval waste storage site is located on the east side of the bay. Two waste transport ships are used for storage and movement of nuclear-contaminated materials from the refit facility.

Sevmorput: The naval shipyard at Sevmorput[a] is located at Rosta on the Kola Fjord, southwest of the Severomorsk headquarters and just north of the City of Murmansk. New and spent fuel assemblies are stored at the shipyard for refueling operations. Spent fuel has been shipped directly from here to Mayak for reprocessing in the past. New fuel assemblies for the entire Northern Fleet are usually stored here until they are picked up by service ships.

Gremikha: Gremikha[a] lies in ice-free waters but has no significant rail or road access. Cutbacks in the Navy's budget have affected the local inhabitants, and many have left the area. Between 17 and 19 decommissioned nuclear submarines are stored here, as well as several officially operational ships waiting for decommissioning. Nuclear waste from refueling operations is also stored on the base.

Severodvinsk: The town of Severodvinsk had 170,000 inhabitants at the end of 1993. There are two major shipyards in Severodvinsk: Sevmash[a] and Zvezdochka[b]. They are located at the north end of the town. The Akula class SSN are constructed at the Sevmash yard. The Yagry Island docks in the Zvezdochka yard are also designated for the dismantlement of SSBNs under START I. Approximately one ship is now being processed at this site per year.

[a] These are also refueling facilities.
[b] Submarine dismantled yards.

SOURCE: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994).

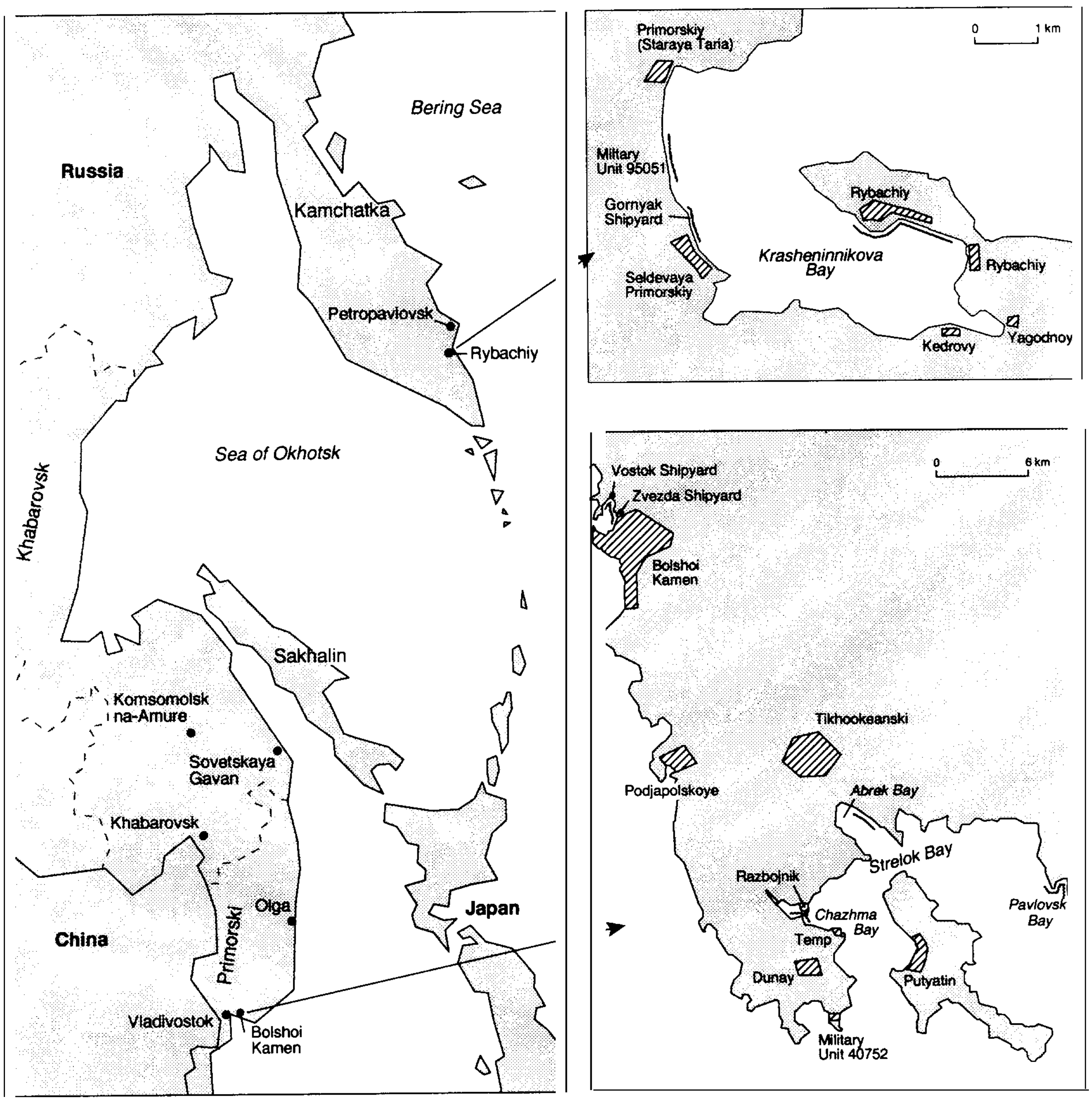
Nuclear waste storage and handling is performed with the assistance of the five support service ships listed in box 4-6. In addition, MSC has storage facilities for low- and medium-level waste. Table 4-3 describes the current status of its five support service ships.

Decommissioning of Nuclear Submarines

The Russian Navy laid up and began to decommission 15 to 25 nuclear submarines per year from 1990 to 1994. Many of these ships had reached the end of their useful life and had outdated weapons systems and power plant technology. If current plans are followed, an average of six nuclear submarines per year will probably be taken out of service by the Russian Navy during the next decade.

Normal operation of the current Russian fleets would require the replacement of about 20 reactor cores per year, 10 for each fleet (49). However, storage facilities currently have room for only several additional reactor cores. The policy of the Russian Navy has been to reserve even this limited core storage space on service ships and shore facilities to refuel *operational* submarines only. Therefore, no spent fuel storage is available for decommissioned submarine reactors. It is likely that spent fuel on decommissioned submarines will not be removed for at least three to five

FIGURE 4-2: Pacific Fleet Nuclear Submarine B



Source: Office of Technology Assessment, adapted from Handler, J., "Russia's Pacific Fleet-Submerine Bases and Facilities," Jane's *Intelligence* ***Review-Europe,*** Apr. 1994

BOX 4-4: Nuclear Submarine Bases of the Russian Pacific Fleet

Krasheninnikova Bay (near Petropavlovsk): Rybachiy is a major nuclear submarine base on the Kamchatka Peninsula. The base is located 15 km southwest of the City of Petropavlovsk across Avachinskaya Bay.

Postovaya Bay (near Sovetskaya Gavan): Further south of the Kamchatka Peninsula in the Khabarovsk Kray is a small town called Zavety Ilyicha. The town is located on Postovaya Bay between the seaport of Vanino and Sovetskaya Gavan. Zavety Ilyicha was a small submarine base during the 1980s. The four submarines operating out of the base were retired in 1990. Their fuel has not yet been offloaded. The Pacific Fleet has committed to removing the submarines. The first was removed in October 1993.

Vladimir Bay (near Olga): This small submarine base is located 300 km northeast of Vladivostok, just south of Olga on the Japan Sea coast. Vladimir Bay is relatively isolated with poor road and rail access. The deep natural harbor is ice free during the winter months. The nuclear submarine facility is located on the north end of the bay. A few submarines still operated from here as of late 1993. Plans to offload fuel from decommissioned submarines were abandoned by the Navy due to protests from local residents.

Strelok Bay (Pavlovsk): A major submarine base is located 65 km southeast of Vladivostok at Pavlovsk. It housed nine SSBNs as of 1990 as well as additional general-purpose nuclear submarines. According to Pacific Fleet press officer Captain First Rank V. Ryzhkov, as of autumn 1992 these older nuclear-powered submarines were awaiting retirement. A report from the Pacific Fleet press office indicates that all of the Yankee and Delta class SSBNs stationed here will be retired. In addition, three submarines damaged in nuclear accidents are stored here. Additional sealed reactor compartments from dismantled submarines are stored at Razbojnik.

Vladivostok: Pacific Fleet headquarters and operations center.

SOURCE: J. Handler, "Trip Report: Greenpeace Visit to Moscow and Russian Far East, July–November 1992: Russian Navy Nuclear Submarine Safety, Construction, Defense Conversion, Decommissioning, and Nuclear Waste Disposal Problems" (Washington, D.C.: Greenpeace, Feb. 15, 1993).

BOX 4-5: Pacific Fleet Shipyards, Repair, Refueling, and Nuclear Waste Storage Facilities

Nuclear submarine facilities are listed from the Kamchatka Peninsula in the North to Vladivostok in the South along the Pacific Coast.

Krasheninnikova Bay (near Rybachiy): A major radioactive waste site for the Pacific Fleet. Is located at the southern end of Krasheninnikova Bay, across from the naval base at Rybachiy. The unit contains three burial trenches for solid radioactive waste, fresh fuel storage, and piers for operating its three refueling support ships and two liquid waste tankers. Shipyard 30 at Gornyak is a nuclear submarine shipyard located in the southwestern corner of the bay.

Shkotovo-22 (Military Unit 40752): On the Shkotovo Peninsula near Dunay is a large waste disposal site. Spent nuclear submarine fuel is usually kept here prior to shipment for reprocessing at Chelyabinsk by rail. This facility has several support ships attached to it.

(continued)

BOX 4-5: Pacific Fleet Shipyards, Repair, Refueling, and Nuclear Waste Storage Facilities (Cont'd.)

Chazhma Ship Repair Facility:[a] Chazhma Bay is a small refit and refueling facility also located near the settlements of Dunay and Temp on the east end of the Shkotovo Peninsula facing Strelok Bay. A serious nuclear incident occurred here on August 10, 1985, during the refueling of an Echo II submarine reactor. While removing the reactor lid, control rods were partially withdrawn accidentally; the reactor overheated and caused an explosion that killed 10 men and contaminated the surrounding environment over an area up to 5 to 30 km from the site.

Zvezda or Bolshoi Kamen:[a] This is a major nuclear submarine overhaul and refueling shipyard. Bolshoi Kamen is a designated submarine dismantlement facility under START I.

[a] Refueling facility.

SOURCE: J. Handler, "Radioactive Waste Situation in the Russian Pacific Fleet," Greenpeace trip report, Nuclear Free Seas Campaign (Washington, D.C.: Greenpeace, Oct. 27, 1994).

BOX 4-6: Service Ships of the Nuclear Icebreaker Fleet

Imandra is a 130-m-long service ship used for storing fresh and spent fuel assemblies. The ship was built by the Admiralty shipyard in St. Petersburg and put into service in 1981. The total capacity of 1,500 assemblies allows the ship to store fuel from up to six icebreaker reactors. The ship uses a dry storage system with waterproof receptacles each holding five fuel assemblies floating in a pool of water.

Lotta is a service ship 122 m long built in 1961. The ship was upgraded in 1993 to handle the transfer of fuel assemblies into the newest railway shipping containers (TUK-18) for spent fuel shipment to Mayak. The ship has 16 sections with 68 containers in each. Used fuel assemblies are stored aboard the *Lotta* for a minimum of three years. The ship has 65 damaged fuel assemblies stored on-board, which cannot be processed by the Mayak facility. These were transferred from the *Imandra* in 1985.

Serebryanka is a 102-m-long tanker used for offloading liquid radioactive waste directly from nuclear-powered icebreakers or the service ship *Imandra.* The ship has eight tanks, each with a capacity of 851 m^3, and was used for discharging liquid waste directly into the Barents Sea until 1986.

The ***Volodarsky*** is the oldest ship in the Murmansk Shipping Company fleet. The 96-m ship was constructed in 1929 and is of riveted steel plate construction. Until 1986 the ship was used to transport solid radioactive waste from Atomflot to the west side of Novaya Zemlya for dumping into the Barents Sea. The ship has 14.5 metric tons of low- and medium-level waste stored aboard.

The ***Lepse*** is a spent fuel service ship of 87-m length built in 1934 and converted in 1962. The *Lepse* is a special case: between 319 and 321 damaged fuel assemblies were stored on the *Lepse*. These fuel assemblies expanded due to lack of proper cooling before they were put in built-in storage locations. The result was that the damaged assemblies could not be removed. They remain aboard the *Lepse*, enclosed within a concrete cover to reduce radiation emissions.

SOURCE: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994).

TABLE 4-3: Spent Fuel, Liquid, and Solid Radioactive Waste Storage at *Atomflot*

Ship	Displacement (metric tons)	Fuel assemblies	Liquid waste (cubic meters)	Solid waste (metric tons)
Imandra	9,500	1,500	545	0
Lotta	N/A	4,080[a]	0	0
Serebryanka	4,000	0	851	0
Volodarskij	5,500	0	0	14.5
Lepse	5,000	642[b]	46	? (36 containers)
Ship storage		6,222	1,442	14.5 (+ 36 containers)
Land storage		0	357	<1 (incinerated)

[a] The capacity is 5,440, or 75% filled with undamaged fuel, of which 840 assemblies are naval fuel.
[b] Of which 50% are not extractable.
KEY: N/A = Not available.

SOURCES: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); O. Bukharin, "Nuclear Fuel Management in the Russian Navy," staff paper prepared for OTA, November 1994.

years after the reactor is shut down, and no additional shipboard or land-based storage will be provided for spent fuel (42).

Refueling Practices

Submarines are refueled according to the schedules authorized by each fleet's commander-in-chief. Under past routine Russian naval operations, refueling was conducted every seven to 10 years and coincided with submarine refit and overhaul.[6] Starting in the 1980s, the Navy also began defueling many retired submarines. In the past, submarines undergoing overhaul at shipyards were refueled in dry docks. However, more recently, the standard approach has been to refuel while floating. Fuel is now changed not at shipyards but with Navy floating refueling facilities (every three to five years) (see table 4-4). Icebreakers are usually refueled every three to four years at the MSC's Atomflot base by using service ships to transfer and store fuel awaiting shipment for reprocessing. Table 4-4 presents a list of 10 refueling facilities operated by the Russian Navy and MSC.

In the Navy, the submarine service ships used for defueling are also known as "floating technical bases" or workshops (see box 4-7). These service ships are known in the West as *PM-124* and *Malina* class submarine support ships. The PM-124 class is a converted Finnish-built cargo barge. In its two steel aft compartments, the ship can carry fuel from approximately two reactor cores (560 fuel assemblies). The PM-124 ships are now about 30 years old and are considered beyond their useful lifetimes.[7]

Three Malina class ships—PM-63 and PM-12 in the north and PM-74 in the Pacific—are relatively modern and can serve nuclear vessels of any type. Malina class ships are the Navy's preferred ships for use in current fuel management operations.[8] (There are, however, problems with the condition of these ships as well.) Malina class ships are equipped with two 15-metric ton cranes to handle reactor cores and equipment; each can carry fuel from approximately six reactor cores (1,400 fuel assemblies).

In a typical refueling operation, the submarine is docked between the submarine service ship and the pier of the refueling facility. (The facility

[6] Refueling of submarines occurs frequently, every two and a half to five years. In case of a reactor accident, fuel management strategy is decided by an expert council.

[7] The PM-48, PM-124 (both based in Kamchatka), and PM-80 (based in Primorye) are out of service because of accidents and worn-out conditions. Only the PM-125 and PM-133 are used for fuel management operations in the Pacific (27).

[8] The years of production of the PM ships are 1984 (PM-63), 1986 (PM-74), and 1991 (PM-12). (35).

TABLE 4-4: Refueling Facilities

Northern Fleet	Pacific Fleet	Murmansk Shipping Company
Zapadnaya Litsa	Zvezda repair yard (Shkotovo-17 near Bolshoi Kamen)	Atomflot base
Nerpa shipyard (Olenya Bay)	Chazhma Bay repair facility (Shkotovo-22, Chazhma Bay)	
Shipyard No. 10 Shkval (Polyarny, Pala Bay)	Shipyard No. 30 at the Gornyak complex (Krasheninnikova Bay)	
Sevmash shipyard (Severodvinsk)		
Gremikha		
Shipyard No. 35 at Sevmorput (Murmansk)[a]		

[a] Because the plant is located near residential areas. refueling activities at Sevmorput were terminated by the Murmansk authorities in 1991. The last refueling took place on December 31, 1991.

SOURCES: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); J. Handler, "The Northern Fleet—Nuclear Submarine Bases," *Jane's Intelligence Review-Europe*, Dec. 1993.

BOX 4-7: Service Ships of the Russian Nuclear Navy

Malina class nuclear submarine support ships are 137-m (450-feet) long, with 10,500-ton displacement. Each ship has a storage capacity of 1,400 fuel assemblies. The ships were constructed by the Nikolayev Shipyard in the Ukraine. Each carries two 15-ton cranes for removal and replacement of fuel assemblies.

PM-63	Northern Fleet	Severodvinsk (1984)
PM-74	Pacific Fleet	Krasheninnikova Bay, Kamchatka (1986)
PM-12	Northern Fleet	Olenya Bay, Zapadnaya Litsa (1991)

PM-124 class (Project 326) lighters are nuclear-submarine support barges with a capacity of 560 fuel assembles each. These units can also store up to 200 m^3 of liquid radioactive waste.

PM-124	Northern Fleet	Zvezdochka shipyard, Severodvinsk
PM-78	Northern Fleet	Zvezdochka shipyard, Severodvinsk
PM[a]	Northern Fleet	Zvezdochka shipyard, Severodvinsk
PM-80	Pacific Fleet	Shkotovo waste site
PM-125	Pacific Fleet	Shkotovo waste site
PM-133	Pacific Fleet	Shkotovo waste site
PM-48	Pacific Fleet	Krasheninnikova Bay, Kamchatka

(continued)

BOX 4-7: Service Ships of the Russian Nuclear Navy (Cont'd.)

Pinega class nuclear-submarine support ships are 122-m (400-feet) long with 5,500-ton displacement. Each is used for transporting liquid radioactive waste. The ships were constructed at Szczecin, Poland.

Amur	Northern Fleet	Pala Guba, Kola Fjord (1986)
Pinega	Pacific Fleet	Bolshoi Kamen, Vladivostok (1987)

Vala class special tankers are 73-m (240 feet) long with a displacement of 2,030 tons. The ships were constructed between 1964 and 1971 for the purpose of transportation and disposal of liquid radioactive waste.

TNT-5	Pacific Fleet	Bolshoi Kamen, Vladivostok
NT-27	Pacific Fleet	Bolshoi Kamen, Vladivostok
TNT-11	Pacific Fleet	Krasheninnikova Bay, Kamchatka
TNT-23	Pacific Fleet	Krasheninnikova Bay, Kamchatka
TNT-12	Northern Fleet	Pala Guba, Kola Fjord
TNT-19	Northern Fleet	Unknown
TNT-29	Northern Fleet	Unknown

[a] Designation unknown.

SOURCES: J. Handler, "Russia's Pacific Fleet—Problems with Nuclear Waste," *Jane's Intelligence Review,* Mar. 1995; J. Handler, "Russia's Pacific Fleet—Submarine Bases and Facilities," *Jane's Intelligence Review-Europe,* Apr. 1994; *Jane's Fighting Ships, 1994–95,* Captain Richard Sharpe (ed.), 97th edition (Surrey, U.K.: Jane's Information Group, 1994); T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994).

provides electric power, fresh water, and other support services.) Refueling begins with the removal of a portion of the submarine hull and lifting of the reactor lid.[9] Measures are taken to prevent release of radioactive aerosols to the environment (26). In the next step, the primary cooling circuit is disconnected and spent fuel is removed from the reactor vessel. Fuel is removed assembly by assembly using the cranes of the service ship with the help of special metal sleeves to shield spent fuel. Spent fuel assemblies are accommodated inside cylindrical cases, which are placed in the storage compartments of the service ship. After defueling, the reactor vessel is cleaned out and the reactor section is overhauled. Reactor waste is loaded on the service ship.[10] Finally (with an operational ship), fresh fuel is inserted into the reactor vessel, the primary cooling circuit is filled with new coolant, the reactor lid is installed to seal the reactor, and the portion of the hull is welded in place.

Typically, it takes approximately one month to defuel, and two to three months to refuel, one submarine (27). (Refueling of an icebreaker is reported to take approximately 45 days. Five to seven days are needed to remove spent fuel, and two to three days to insert fresh fuel; the remainder is required for auxiliary operations (53).

[9] Immediately after reactor shutdown and prior to refueling, fuel is kept in a reactor core to allow for decay of short-lived fission products. During this initial period cooling of the fuel is provided by reactor pumps.

[10] Liquid waste—50–80 metric tons of washing water, etc., from a twin-reactor propulsion unit—is filtered and discharged into the sea. Solid waste (155–200 cubic meters) and spent fuel (2–3 cubic meters) are stored aboard the service ship.

Refueling Problems

The rate of refueling operations has declined following reductions in operational schedules for the Russian nuclear fleet. For example, with a refueling capacity of four to five submarines per year, the Pacific Fleet in the past refueled three to four submarines per year. In 1994 and early 1995, spent fuel was removed from only one decommissioned submarine (11).[11] The Navy is facing significant delays in defueling/refueling submarines due to the following problems:

1. *Lack of fuel transfer and storage equipment:* In the past, many pieces of refueling and spent fuel storage equipment were produced outside Russia. The breakup of the Soviet Union and dissolution of the Warsaw Pact have interrupted the equipment supply. For example, Malina class submarine service ships were produced at the Nikolayev shipyard in Ukraine. A new Malina class ship for the Pacific Fleet had been ordered from Nikolayev. Because of the breakup of the Soviet Union, construction was never completed.
2. *Saturation of the spent fuel storage capacity:* Because the central storage facilities and some submarine support ships are full (see below), they cannot take any newly removed spent fuel. After submarine reactors are shut down, it is necessary to keep auxiliary cooling systems running to remove heat generated within the reactor core. To accomplish this heat removal, it is likely that circulation within both of the reactor coolant loops must be maintained at a reduced level. Many Russian submarines thus will have such continued standby operations in place for many years. This creates further risks of accidents or unintentional releases of radionuclides in the future.
3. *Difficulties of removing fuel from submarines with damaged reactor cores:* There are three submarines in the Pacific that cannot be defueled because of damaged reactor cores. Experts believe that major portions of these submarines will have to be treated as waste and buried. The work requires significant R&D and has not been started.

Radioactive Waste Disposal

Reactor compartments that have been prepared for flotation are currently stored near naval bases or beached in several locations on the Kola Peninsula and along the Pacific Coast from Vladivostok north to the Kamchatka Peninsula. In recent years, once the reactor compartment has been sealed, the Russian Navy has stored the reactors floating in open bays or along rivers near naval bases. To provide greater flotation, one additional sealed compartment on each end of the reactor compartment remains attached to the package. The advantages of this method are that the sealed package is less likely to sink than the entire submarine, and it is easier to handle and transport by water. Disadvantages include the possibility that over periods of decades to hundreds of years, seawater corrosion will penetrate the sealed reactor compartment and allow the exchange of water with the environment. In the United States, dismantled submarine reactor compartments are sealed and shipped to a dry, shallow, land burial site in Hanford, Washington.

Several Russian studies have proposed various methods for establishing reactor compartment disposal facilities. These include placing reactor compartments in concrete-lined trenches or in underground storage (42). One plan is to put some reactor compartments in tunnels near submarine bases in the north and Far East. However, the prospects for implementation of this program remain uncertain. The Russian regions of Murmansk and Arkhangel'sk have reportedly agreed to the siting of permanent storage facilities for radioactive waste on the southwestern tip of the island of Novaya Zemlya at the Bashmachnaya Bay (48).

[11] It has been reported that only one defueling/refueling operation was conducted in 1993 in the Pacific Fleet, compared to five refuelings and three defuelings in 1990 (27).

In a recent meeting of regional authorities,[12] Russian officials decided to pursue studies related to the development of a long-term solid waste storage facility on Novaya Zemlya. The facility would consist of deep burial trenches covered with gravel. The proposed site is located on Bashmachnaya Bay, on the southwestern part of Yuzhny Island.

Evaluations were previously conducted of five potential sites on the Kola Peninsula. A site at Guba Ivanovskaya near Gremikha was chosen and subsequently rejected by GAN.

Some Russian geologists believe that permafrost is a suitable storage medium for high-level solid waste. Novaya Zemlya permafrost is 200 meters thick, stable over the long term, with no water migration. However, Western opinion is more skeptical. The Bellona Foundation notes that the facility will have to be far more complex than a simple "hole in the ground."

Dismantlement of Submarine Hulls

In recent years the Russian Navy has been dismantling decommissioned nuclear submarines at several sites. Dismantlement takes place in Northern Fleet facilities on the Kola Peninsula and Arkhangel'sk (Nerpa and Zvezdochka yards) and in Pacific Fleet facilities in the Vladivostok area (Bolshoi Kamen yard). A review of the decommissioning procedures used by the Russians, as well as the status of the activities, is presented below.

The U.S. Navy is also conducting a major nuclear submarine dismantlement program. The current program began in 1992 and calls for the United States to dismantle completely 100 nuclear submarines at a total cost of approximately $2.7 billion (30). The U.S. program, unlike the current Russian activity, will result in burying sealed reactor compartments in an underground site at the Hanford, Washington, nuclear facility run by the Department of Energy. The remainder of the U.S. submarine hulls and equipment will be disassembled, cut into pieces, and either recycled, scrapped, or treated as hazardous waste. Spent fuel removed from dismantled U.S. nuclear submarines is currently being stored at the dismantlement shipyard on Puget Sound, Washington, awaiting the results of an Environmental Impact Statement to determine where long-term storage facilities will be located.

The Zvezdochka shipyard at Yagry Island in Severodvinsk and the Nerpa repair yard on Olenya Bay are the primary facilities for dismantlement of Russian Northern Fleet nuclear submarines. The Russian Pacific Fleet has also begun dismantling submarines at the Bolshoi Kamen shipyard near Vladivostok. As of January 1995, only 15 of the retired submarines had been dismantled completely. A total of 101 submarines in both fleets are in various stages of decommissioning (see table 4-2). Seventy of these decommissioned submarines had *not* had spent fuel removed from their reactors. Although a large number of submarines have been decommissioned, the defueling and dismantling process has been slow. Some of the decommissioned submarines have been out of service with spent nuclear fuel still on-board for more than 15 years (30). By the end of 1994 there were 20 additional submarines classified by Western sources as in service which were actually laid up (see table 4-5).

Between 1995 and 2003, this backlog is expected to continue to grow.[13] An additional 70 to 80 submarines will probably be decommissioned due to both age and consolidation of the fleet. The total number of decommissioned submarines could increase to around 180. At the current rate of dismantlement—about five per year—it will take one to two decades to complete dismantlement of all of the nuclear submarines that will be decommissioned by the year 2003.

[12] A meeting of the interagency Committee for Ecology of Murmansk was held at the Murmansk City Hall on June 21, 1995. The committee was briefed by MSC, the Kola Nuclear Power Plant, the Russian Navy, and government officials from the region.

[13] The decommissioning rate will be slower than in the past several years. Refer to table 4-2 for a more detailed explanation of the projected composition of the Russian nuclear fleet.

TABLE 4-5: Russian Nuclear Submarines Decommisioned as of January 1995
Northern and Pacific Fleets

Status of decommissioned nuclear submarines	Total	Northern Fleet	Pacific Fleet
Dismantled and defueled	15	6	9
Defueled (waiting for dismantlement) or sunk	36	20	16
Decommissioned or laid-up (with fuel on board)	70	44	26
Total submarines out of service	121[a]	70	51

[a] Table 4-2 which is based on Western sources of information, indicates that 101 nuclear submarines were retired from service as of January 1, 1995. The additional 20 nuclear subs should be classified as "in-service, inactive" according to the Russian sources cited above. These vessels are currently laid-up and planned for decommissioning.

SOURCES: V. Litovkin, "93 Nuclear Submarines," *Izvestia*, July 9, 1993:6; V. Danilian and V.L. Vysotsky, "Problems of Spent Nuclear Fuel Management in the Pacific Fleet of the Russian Navy," paper presented at the OTA Workshop on Spent Nuclear Fuel and Waste Management, Jan. 17–18, 1995, Washington, D.C.; G. Baham, "Nuclear Fleet of the fSU: A Preliminary Analysis of Dismantlement Activities," Staff Paper prepared for OTA, February 1995; Gosatomnadzor, "Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," approved by Order of the Russian Federal Nuclear Inspectorate [Gosatomnadzor] No. 61 from May 13, 1994, translated by Greenpeace International; North Atlantic Treaty Organization, Committee on the Challenges of Modern Society, *Cross-Border Environmental Problems Emanating from Defense-Related Installations and Activities*, Final Report, Volume I: Radioactive Contamination, Phase I: 1993–1995 (Kjeller, Norway: NATO, 1995).

The Nerpa shipyard, located in Olenya Bay, is planning to expand its submarine dismantling facilities to accommodate new equipment provided by the United States, using Nunn-Lugar funds. The goal is to expand processing at Nerpa to dismantle up to five submarines per year. The first submarine dismantled by Nerpa in early 1995 took five months for the reactor compartment to be cut out of the hull and prepared for flotation.

MANAGING SPENT FUEL FROM THE RUSSIAN FLEET: ISSUES AND OPPORTUNITIES FOR COOPERATION

A key activity associated with the Russian nuclear fleet of submarines and icebreakers is management of the nuclear fuel. During normal operations of the fleet, each reactor must be refueled periodically. And when submarines and other ships are being dismantled—as they are now—the spent fuel must be removed and stored or processed in some way. This spent nuclear fuel is highly radioactive, and accidents or releases of radioactivity are possible during the multiple steps required unless all parts of the system are technologically sound and operated under high standards of safety and protection. Russian naval reactors and fuels represent a variety of designs and manufactures and therefore present unique handling, storage, and disposal problems. Box 4-8 describes the reactor and fuel designs (see table 4-6), and box 4-9 discusses the integration of naval fuel into the Russian national nuclear fuel cycle. Figure 4-3 presents a schematic diagram of the Russian naval nuclear fuel management process.

Other problems are evident with service ships and land-based facilities that were designed for interim storage and are now used for long-term storage. Also, submarines that were to be defueled immediately after being taken out of service have become long-term spent fuel storage facilities themselves. An approach that would include safety and operational analyses reflecting changes in facility missions has not been developed.

BOX 4-8: Naval Reactor and Fuel Designs

Soviet/Russian submarines have been equipped with reactors of several designs. Several submarines of the November and Alfa classes were powered with lead-bismuth-cooled reactors (liquid metal reactors, LMRs). High power density in an LMR and its compact design allowed reduction in submarine size while retaining the power of the naval propulsion unit. As a result, Alfa class ships were very fast. However, maintenance problems associated with neutron activation in bismuth and reactor accidents have led to early retirement of the LMR-powered submarines.[a]

At present, probably all nuclear-powered vessels in Russia use one or two pressurized water reactors (PWRs). There are three generations of naval PWRs. Reactors of the first generation were deployed between 1957 and 1968, and all have been decommissioned. Reactors of the second generation were deployed between 1968 and 1987 with many still in service; third-generation reactors have been installed on submarines since 1987. The best described is a 135-MW KLT-40 reactor, which has been installed on icebreakers since 1970. This is a pressurized water reactor with the following principal components: a pressure vessel, a reactor lid that carries five reactivity control assemblies and four actuators for an emergency core cooling system, and a fuel core. Steam for the propulsion unit is produced in four vertical steam generators. It is thought that submarine reactors have designs similar to that of KLT-40 but are smaller in size.

It is believed that a reactor core consists of 180 to 270 fuel assemblies, containing several fuel rods each. In older designs, fuel rods were round. Newer reactor core designs utilize fuel rods of cross, plate, or cane shapes.[b] The level of enrichment of uranium fuel varies significantly depending on reactor core design. (Apparently, a reactor system of a specific design may use reactor cores of different types.) Reactors of the first and second generations were fueled with 21 percent uranium-235 (U-235). Reactors of the third generation have cores consisting of two to three enrichment zones, with enrichment levels varying between 21 and 45 percent U-235. Standard naval reactor fuel in Russia is stainless steel- or zirconium-clad Cermet material (dispersed fuel), in which uranium dioxide particles are embedded in a nonfissile aluminum matrix.[c]

Some reactors are fueled with weapons-grade (more than 90 percent U-235) or near-weapons-grade (70 to 80 percent U-235) uranium. For example, liquid metal reactors were almost certainly fueled with weapons-grade uranium. Also, some icebreaker fuels are zirconium-clad, uranium-zirconium metallic alloys with uranium enriched to 90 percent U-235.[d] (Also, at times, reactors might have been fueled with experimental fuels whose enrichment could differ significantly from that of regular fuel for this type of reactor core.)

Some reactors, however, are fueled with relatively low enriched uranium: for example, in the proposed design of a floating desalination facility, two KLT-40 reactors of the facility's power unit are designed to be fueled with 1.8 metric tons of uranium dioxide enriched to 8.5 to 10 percent U-235.

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[a] One common failure mode involved localized overcooling and solidification of the coolant.

[b] Such shapes increase the surface of fuel rods and, in this way, improve the core's heat transfer characteristics.

[c] Typically, Cermet fuels offer better mechanical integrity, swelling resistance, and containment of fission products than uranium alloys. They also have superior heat conductivity when compared with uranium ceramics.

[d] For example, HEU-fueled icebreakers have cores containing 151 kg of 90 percent enriched uranium. According to reactor designers, the reactor of the nuclear-powered ship *Sevmorput* is fueled with 200 kg of 90 percent enriched uranium.

SOURCES: V. Kovalenko, "Braving the Chill of the Market," *Nuclear Engineering International*, Jan. 1993; J. Handler, Greenpeace, personal communication, October 1994; U.S. Department of Energy, Office of Foreign Intelligence, *Radioactive Waste Management in the Former USSR: Volume III*, prepared by D.J. Bradley, PNL-8074 (Richland, WA: Pacific Northwest Laboratory, 1992); O. Bukharin, "Nuclear Fuel Management in the Russian Navy," Staff Paper prepared for OTA, November 1994.

TABLE 4-6: Russian Nuclear Naval Propulsion Reactor Design

Type of vessel	Number / type reactors	Power per reactor, MW_t	Fuel enrichment, percentage Uranium-235
Submarines, first generation (1958 to 1968)			
Hotel, Echo, November	2 PWR / VM-A	70 MWt	20
Submarines, second generation (1968 to present)			
Charlie	1 PWR / VM-4	70 to 90	20
Victor, Delta, Yankee	2 PWR / mod VM-4		
Submarines, third generation (1987 to present)			
Typhoon, Oscar	2 PWR / OK-650	190	20 to 45
Akula, Sierra, Mike	1 PWR / OK-650		
Other submarines			
Papa (1969 to late 1980s)	2 PWR / unknown	177	unknown
November-645 (1963 to 1968)	2 LMR / VT-1	73	weapon-grade
Alfa (1969 to present)	2 LMR / OK-550 or BM-40A	155	weapon-grade
X-Ray, Uniform, AC-12 (1982 to present)	1 PWR / unknown	10 (X-Ray)	unknown
Cruisers (1980 to present)			
Kirov	2 PWR / KN-3	300	unknown
Auxiliary ships (1988 to present)			
Kapusta	2 PWR / unknown	171	unknown
Sevmorput	1 PWR / KLT-40	135	up to 90
Icebreakers			
Lenin (1959 to 65)	2-3 PWR / OK-150 and OK-900	90	5
Arctica (1975 to present)	2 PWR / KLT-40	135	up to 90
Taymyr (1989 to present)	1 PWR / KLT-40	135	up to 90

KEY: PWR=pressurized water reactor; LMR-liquid metal reactor

SOURCE: O. Bukharin, "Nuclear Fuel Management in the Russian Navy," staff paper prepared for OTA, November 1994.

BOX 4-9: Naval Fuel: Integration into the National Nuclear Fuel Cycle

The naval fuel cycle is closely integrated with the nuclear fuel cycles of military material production reactors and commercial nuclear power reactors. For a significant fraction of naval reactor fuel, the design of the fuel cycle was as follows:

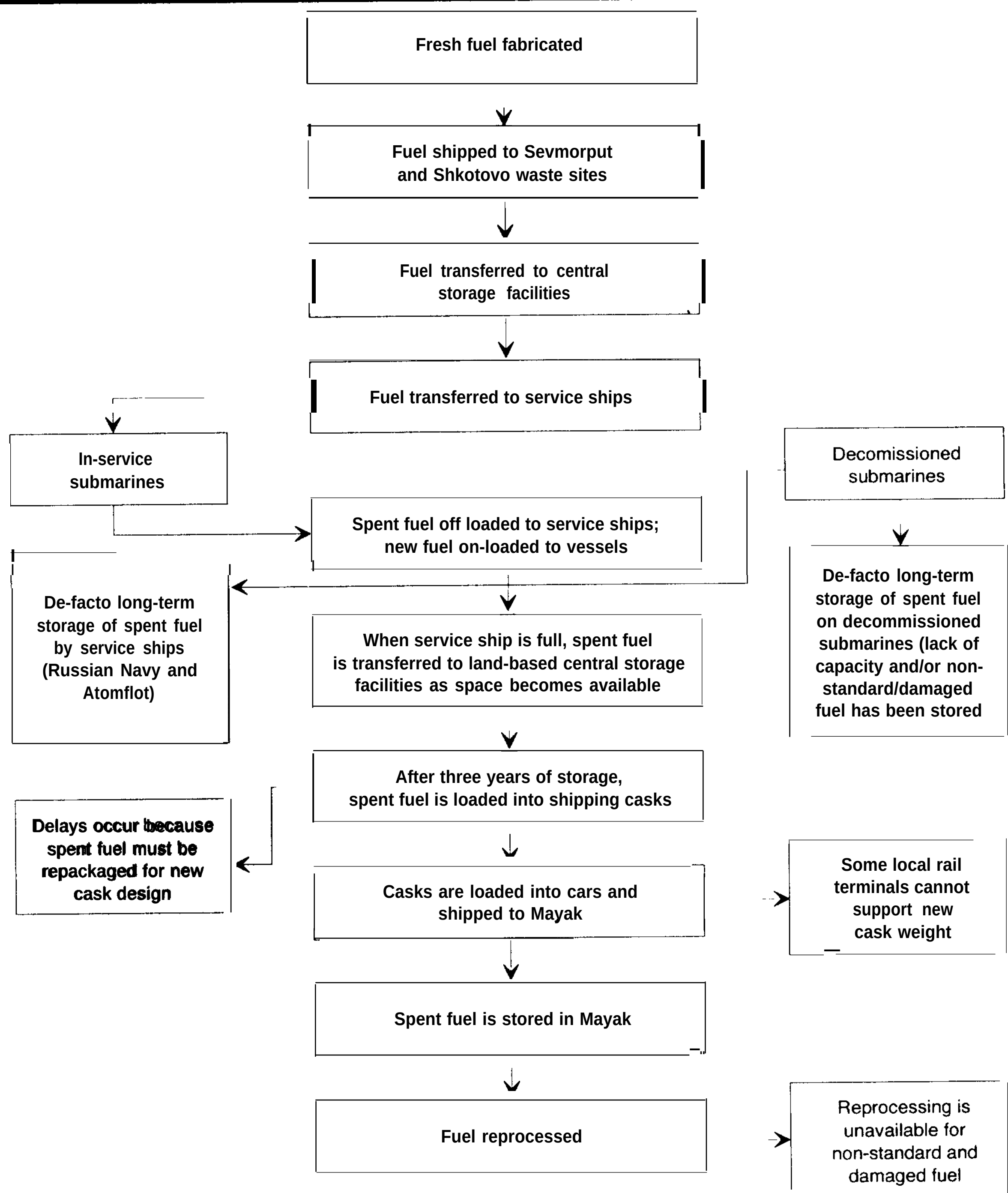
- Uranium feed for naval fuel was produced by recovering uranium from irradiated Highly Enriched Uranium (HEU) fuel from two tritium production reactors at Mayak (Chelyabinsk-65) and HEU spike rods from plutonium production reactors in Krasnoyarsk-26 and Tomsk-7.
- Irradiated HEU fuel was reprocessed at the RT-1 plant at Chelyabinsk-65.
- Recovered uranium (approximately 50 percent enriched) was sent to the Machine-Building Plant at Electrostal near Moscow for fabrication into fuel rods and assemblies.
- After irradiation in a reactor and a few years of temporary storage, fuel was sent to Mayak for reprocessing.
- Naval reactor fuel was reprocessed together with spent fuel from research, BN-350/600, and VVER-440 reactors.
- Separated plutonium was placed in storage at the Mayak site.
- Recovered uranium was sent to the Ust'-Kamenogorsk plant for fabrication into fuel pellets of RBMK reactors.

The fuel cycle design was different for weapons-grade uranium fuel. HEU feed was derived from the national stocks. Approximately 1.5 metric tons of HEU were used for fabrication of naval and research reactor fuel annually. Some of this fuel was reprocessed after irradiation.

This nuclear fuel cycle scheme worked reliably until the early 1990s, when the disintegration of the Soviet Union and reductions in military requirements resulted in remarkable changes. Naval fuel requirements have dropped to a few reactor cores per year. (Reportedly, in 1994, the Murmansk Shipping Company, which procures approximately two reactor cores of fresh fuel per year, became the principal customer at the Electrostal naval fuel production line.) Also, in 1992, the Ust'-Kamenogorsk fuel fabrication plant terminated fabrication of reactor fuel using reprocessed uranium.

SOURCES: E. Mikerin, Information provided at Workshop in Rome, June 1992; E. Mikerin, MINATOM, personal communication, May 1992.

FIGURE 4-3: Russian Naval Reactor Fuel Cycle - Key Steps



Source: Office of Technology Assessment, 1995

Management of Spent Fuel

Institutional Arrangements

Naval fuel management in Russia involves the work of several executive agencies and is regulated by GOSATOMNADZOR, the national nuclear regulatory agency (see box 4-10). The lines of responsibilities for fuel management operations are not always obvious. MINATOM is responsible for fresh fuel until it is delivered to the Navy, GOSCOMOBORONPROM, or the MSC. (Reportedly, in the case of a new submarine, fresh fuel is controlled by GOSCOMOBORONPROM until it is loaded into the reactor at a GOSCOMOBORONPROM shipyard in the presence of Navy representatives. After that, responsibility for the submarine and the fuel is assumed by the Navy. (In other cases, the Navy is responsible for fuel from the moment it arrives at the central storage facility to the moment spent fuel is returned to Mayak.) The responsibility for transportation is shared by the Navy, MINATOM, and the Ministry of Railways. After the spent fuel has arrived at Mayak, MINATOM is solely responsible for subsequent operations (reprocessing, etc.). Similar arrangements exist between MINATOM and MSC.

BOX 4-10: Russian Entities with Responsibility for Navy Nuclear Reactors and Fuel

1. *Ministry of Atomic Energy (MINATOM)*: MINATOM's Main Directorates of Nuclear Reactors, Fuel Production, and Isotope Production, and others are involved in virtually all stages of the naval fuel cycle. Specifically, MINATOM's responsibilities include the following:

- R&D of reactors and fuels;
- development of an infrastructure to support reactor and fuel operations;
- production of naval fuel;
- production and use of spent fuel shipping casks;
- reprocessing of spent fuel; and
- development of a regulatory framework for fuel management and coordination of regulatory activities with Gosatomnadzor.

2. *The Navy (Ministry of Defense)*: The Navy assumes responsibility for fuel from the moment it arrives at a central storage facility until it is shipped to Mayak for reprocessing. Specifically, the Navy is responsible for the safety, security, and quality of the following operations:

- storage of fresh fuel;
- refueling and defueling;
- reactor use of fuel;
- interim storage of spent fuel; and
- loading of fuel into shipping casks and shipping fuel to Mayak.[a]

3. *Murmansk Shipping Company (Ministry of Transportation)*: The company is a private enterprise. However, its nuclear icebreaker fleet remains federal property. Its fuel management responsibilities are similar to those of the Navy.

4. *State Committee for Defense Industries (Goscomoboronprom)*: The Committee's Department of Shipbuilding operates all major shipyards and is responsible for loading fresh fuel into newly built submarines and submarines undergoing major overhaul. The committee's research institutes and design bureaus (e.g., Krylov's Institute of Shipbuilding) are responsible for the integration of reactor systems and fuel management with the technologies and operations of naval vessels.

5. *Ministry of Railways*: The Ministry's Department of Special Cargo shares responsibility for transportation of fresh and spent fuel.

(continued)

BOX 4-10: Russian Entities with Responsibility for Navy Nuclear Reactors and Fuel (Cont'd.)

6. *State Committee for the Supervision of Radiation and Nuclear Safety (Gosatomnadzor)*: The Committee is charged with developing nuclear and radiation safety rules and standards, supervising nuclear safeguards, licensing and inspecting nuclear installations, and coordinating and supporting safety-related research. Gosatomnadzor reports directly to the President. The principal divisions of Gosatomnadzor, involved in the supervision of naval fuel management, include the headquarters' departments of transport reactors, fuel cycle facilities, radiation safety, and material control and accounting, as well as the regional offices of the North-West, Ural, and Central districts. Gosatomnadzor monitors fabrication of naval fuel, refueling, spent fuel storage, shipment, and reprocessing. Gosatomnadzor coordinates these activities, with the Ministry of Environment, Ministry of Health, Committee for Epidemiological Protection, MINATOM, and the Ministry of Defense. As of 1994, Gosatomnadzor was complaining about the lack of cooperation from the Navy.[b] However, the strength of the Committee is increasing as testified by its role in addressing the issues of naval fuel shipments and storage.

[a] Reportedly, the Navy provides the guard force to escort spent fuel shipments. MINATOM (Mayak) owns the shipping casks.
[b] As of May 1994, the Ministry of Defense denied Gosatomnadzor access to its naval vessels.

SOURCES: O. Bukharin, "Nuclear Fuel Management in the Russian Navy," Staff Paper prepared for OTA, November 1994; J. Handler, "Radioactive Waste Situation in the Russian Pacific Fleet," Greenpeace trip report, Nuclear Free Seas Campaign (Washington, D.C.: Greenpeace, Oct. 27, 1994); Gosatomnadzor, "Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," approved by Order of the Russian Federal Nuclear Inspectorate [Gosatomnadzor] No. 61 from May 13, 1994, translated by Greenpeace International.

There is another mechanism for organizing the interagency work. The Russian government's decree on the national program of radioactive waste management (No. 824, 14 August 1993) designated MINATOM as a principal state customer for the program. In this capacity, MINATOM has contracted with the Ministry of Defense, Ministry of Environmental Protection, GOSCOMOBORONPROM, GOSATOMNADZOR, and other agencies to carry out projects related to spent fuel management. The Ministry of Finance was to provide MINATOM with the required funding. The mechanism, however, does not work very well. For example, because of the lack of funding, MINATOM has not been able to pay contractors for the work they have done.

Storage of Spent Fuel in the Navy

The Russian Navy is expected to have a backlog of 300 to 350 cores of spent fuel by the year 2000. Both land-based facilities and service ships or barges are used for temporary spent fuel storage for the Russian nuclear fleet. The service ships are the same ones used for at-sea defueling/refueling. In early 1993, it was reported that about 30,000 spent fuel elements, equal to 140 reactor cores, were in storage in the various facilities of the Russian Northern and Pacific Fleets. Table 4-7 summarizes the spent fuel status in both fleets.

Immediately after its removal from submarine reactors, spent fuel is put in containers—steel cylinders with lead tops. Containers are used both for interim storage of fuel and as part of the spent fuel shipping casks. On service ships, fuel is usually stored in dry, water-cooled compartments in which watertight containers with fuel are suspended from the ceiling in tanks filled with cooling water.

After a service ship is filled to capacity, fuel is transferred to the land-based central sites at the Zapadnaya Litsa and Gremikha bases in the North and the Shkotovo waste site in the Pacific. In the past, most fuel assemblies were directly exposed to cooling water (and, later, encased fuel assemblies). Safe handling of the fuel in temporary storage requires complex monitoring and

TABLE 4-7: Spent Fuel Storage Facilities

Site	Storage facility	Storage fuel assemblies[a]
Northern Fleet:		
Zapadnaya Litsa, Kola Peninsula	Two land-based concrete tanks (another tank is not operational)	20,489
	PM-124 class service ship[b]	560
	Malina class PM-12	1,400
Gremikha,[c] Kola Peninsula	N/A	N/A
Zvezdochka, Severodvinsk	Three PM-124 class service ships	1,680
	Malina class PM-63	1,400
Atomflot, Murmansk	*Lotta* service ship (submarine fuel)	476
Murmansk Shipping Company (MSC):		
Atomflot base, Murmansk	*Imandra* service ship	1,500
	Lotta service ship	5,440
	Lepse service ship	621
Pacific Fleet:		
Shkotovo waste site (military unit 40752), Primorye	Land-based storage	8,400
	Three PM-124 class service ships[d]	1,680
Kamchatka waste site (military unit 95051), Kamchatka	One PM-124 service ship	560
	Malina class PM-174	1,400

[a] The numbers for the Northern Fleet and MSC are from the Bellona report (pp. 45-47). The Yablokov report estimates 21,000 fuel assemblies stored in the Northern Fleet (3,000 containers with seven fuel assemblies each) and 8,400 fuel assemblies (1,200 containers) in the Pacific Fleet. According to the report, the stores are overloaded.

[b] PM class ships are designed for short-term storage of spent fuel. In some cases, fuel has been on these ships for long periods of time.

[c] LMR fuel is believed to be stored at Gremikha.

[d] The PM-80 (Shkotovo) and PM-32 (Kamchatka) hold 118 and 32 damaged fuel assemblies, respectively, that are difficult to remove (Gosatomnadzor, "Report on Activity of Russia's Federal Inspectorate for Nuclear and Radiation Safety in 1993," approved by Order of the Russian Federal Nuclear Inspectorate [Gosatomnadzor] No. 61 from May 13, 1994, translated by Greenpeace International).

KEY: N/A = Not available.

SOURCES: T. Nilsen and N. Bøhmer, "Sources to Radioactive Contamination in Murmansk and Archangelsk Counties," Report Vol. 1 (Oslo, Norway: Bellona Foundation, 1994); Government Commission on Matters Related to Radioactive Waste Disposal at Sea ("Yablokov commission"), created by Decree No. 613 of the Russian Federation President, October 24, 1992, *Facts and Problems Related to Radioactive Waste Disposal in Seas Adjacent to the Territory of the Russian Federation* (Moscow, Russia: 1993), translated by Paul Gallager and Elena Bloomstein (Albuquerque, NM: Small World Publishers, Inc.).

auxiliary systems. The water pool must be provided with a supply of cold water or an internal cooling system. A system is needed to remove contaminants that would accelerate corrosion of the spent fuel. The system must be monitored for radiation to detect leaks. Leaking fuel requires special handling. This process also produces a significant amount of radioactive waste. Finally, any leaks from the pool to the environment must be prevented (49). Storage accidents due to thermal stresses in fuel and corrosion of storage equipment have led the Navy to move most fuel into dry storage.[14] (The Northern Fleet retains some land-based wet storage capacity.)

At the Shkotovo waste site in the Pacific, spent fuel is stored in a horizontal array of cylindrical cells in a concrete floor of the storage building. Each cell accommodates a container with seven fuel assemblies. Presently, 1,075 out of 1,200 cells are loaded with spent fuel. At Zapadnaya Litsa, fuel has been moved into storage facilities designed to hold liquid radioactive waste. (The buildings have never been used for waste storage because liquid waste was previously discharged into the sea.)

As of the end of 1993, spent fuel had been removed from 36 out of 103 decommissioned submarines.[15] The high rates of submarine deactivation and low defueling capacity of the Navy mean that many tens of reactor cores of spent fuel will remain inside shutdown reactors of floating submarines for a long time.

Spent Fuel Storage at the Murmansk Shipping Company

The Murmansk Shipping Company (MSC) is a private Russian enterprise engaged in the operation of nuclear-powered icebreakers and other commercial ships. MSC currently performs all spent fuel management related to its icebreakers. Discharged icebreaker fuel is initially stored onboard the service ship *Imandra* (capacity 1,500 fuel assemblies), which is designed to refuel icebreakers at the Atomflot base.[16] After approximately six months of storage on the *Imandra*, fuel is transferred to the service ship *Lotta* (capacity 5,440 fuel assemblies).[17] *Lotta*, like *Imandra*, is an ice-class vessel. *Lotta* has been equipped to handle the new TUK-18 fuel casks. Spent fuel is stored aboard *Lotta* for two to three years. On both *Imandra* and *Lotta*, fuel is stored in dry, water-cooled storage (as described above).[18] The ships are relatively modern and in good condition.

The service ship *Lepse*, however, is older and not as well maintained. It also contains a large amount of highly contaminated damaged fuel. The *Lepse* has 643 fuel assemblies aboard. No additional spent fuel has been loaded on the *Lepse* since 1982. One of the two *Lepse* storage compartments contains spent fuel from the damaged core of the icebreaker *Lenin*.[19] To control radiation releases from damaged fuel assemblies, the entire storage section, which contains 317 fuel assemblies, was encased in concrete. The other compartment also contains a large amount of damaged fuel, about 30 percent of the 643 fuel assemblies. Thus, between 80 to 90 percent of the spent fuel aboard the *Lepse* is either damaged or nonextractable because it has been encased in concrete. To develop a remediation plan for it, MSC must inventory the remaining accessible spent fuel to determine which fuel assemblies, if any, are removable using existing equipment.

MSC was also constructing a land-based storage facility for interim (20 to 25 years) storage of spent fuel. The building was 90 percent complete when the Russian nuclear regulatory agency,

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[14] In 1986, corrosion of fuel handling and storage equipment led to a serious accident at the storage facility at Zapadnaya Litsa (built in the early 1970s). Because of corrosion, several containers with spent fuel fell to the bottom of the storage tank and some of them broke. The accident resulted in a severe contamination problem and had the potential for a nuclear criticality event. (Experts of the Physics and Power Institute in Obninsk have evaluated the probability of a criticality event for such an accident and found it to be small.)

[15] According to Captain V.A.Danilian, the Pacific Fleet has decommissioned 51 submarines (including three with damaged reactor cores) and has defueled 22 submarines [OTA workshop Jan 17–19, Washington D.C.].

[16] *Imandra's* storage capacity consists of six steel compartments, each holding 50 containers for 250 fuel assemblies.

[17] The *Lotta* has 16 storage compartments; each compartment has 68 containers containing five fuel assemblies. Since the mid-1980s, 168 of *Lotta's* containers (840 fuel assemblies) have been used to store submarine fuel.

[18] Thirteen containers (65 fuel assemblies) are not cooled (48).

[19] Reportedly, 319 to 321 fuel assemblies from the icebreaker *Lenin* are stored on the *Lepse*; of these, 10 to 20 fuel assemblies are estimated to be seriously damaged.

GOSATOMNADZOR, indicated that it will not authorize its operation unless the facility is rebuilt to meet modern safety requirements.[20] MSC is now reconstituting its plans for an interim spent fuel storage facility to serve both the icebreakers and the Northern Naval Fleet. Two key issues that must be addressed with a new storage facility are the disposition of zirconium-uranium (Zr-U) fuel and damaged fuel now stored aboard service ships. Neither type of fuel can be reprocessed currently at Mayak, and no long-term storage is available.

MSC projects that there will be 13 cores of Zr-U fuel aboard its service ships within three to five years. Therefore, unless this fuel is moved to a land-based storage site at Atomflot, it prevents MSC from conducting normal refueling operations for its icebreakers. One plan under consideration is to use the *Lotta* to transfer the Zr-U fuel to newly acquired dry storage casks (possibly of Western design), which could then be stored safely at Atomflot.

A new MSC storage facility could also be used to store any damaged fuel removed from the *Lepse*. In June 1995, MSC tendered an engineering study of options for cleaning up the *Lepse*. The European Union (EU) has provided $320,000 for engineering work in support of this effort. The goal of the effort is to inventory completely the spent fuel, perform a risk assessment, and suggest options for a course of action. Although Western contractors will be involved in the effort, MSC has insisted that any research and engineering work specifically include Russian subcontractors: OKBM (fuel design), Kurchatov Institute (science director), and VNII[21] Promtechnologia (waste disposal). The U.S. Environmental Protection Agency (EPA) is considering supporting the risk assessment phase of the project.

Shipment and Disposition of Spent Fuel from the Russian Nuclear Fleet

Spent Fuel Shipment

Spent fuel from the Russian nuclear fleet has regularly been shipped to reprocessing facilities. After one to three years of storage, the standard practice is to ship naval spent fuel to the RT-1 plant at Mayak for reprocessing. In the past, spent fuel was shipped from the facilities at Zapadnaya Litsa, Sevmorput', and Severodvinsk in the North. In the Pacific Fleet, fuel was shipped from an installation, a short distance away from the Shkotovo waste site (27).

At storage facilities, containers with spent fuel were loaded by cranes into shipping casks and delivered to rail terminals for loading on specially designed flatbed cars. The cars were formed in a special train and sent on a several-day journey to Mayak.

In the past, the principal types of shipping casks in use were TUK-11 and TUK-12 (see table 4-8). One train with TUK-11/12 casks could carry approximately 500 fuel assemblies. The TUK-11 and TUK-12 casks were manufactured between 1967 and 1985. GOSATOMNADZOR banned their use in October 1993 because of the following safety concerns: 1) vulnerability of the casks to low temperature (below -5°C); 2) potential for cask rupture in an accident involving a head-on collision or car toppling; 3) inadequate quality of production of the casks; and 4) worn-out conditions of the casks, railcars, and railway equipment (22).

Recently, the obsolete TUK-11 and TUK-12 casks have been replaced by new casks of the TUK-18 type. One train of TUK-18 casks carries approximately 600 fuel assemblies, an equivalent of 1.5-2 reactor cores of spent fuel. TUK-18 casks also meet international standards and can withstand serious rail accidents. The Northern and Pacific Fleets have received 18 and 32 new casks, respectively. The number of casks is suffi-

[20] According to GOSATOMNADZOR, the facility would not survive an airplane crash or other similar disaster (53).
[21] All Russian Scientific Research Institute.

TABLE 4-8: Spent Fuel Shipping Casks

	TUK-11	TUK-12	TUK-18
Designation of fuel containers/number of containers per shipping cask	22 or 22M/one container	24 or 24M/one container	ChT-4/ seven containers
Number of fuel assemblies per container/number of containers per shipping cask	7/7	7/7	7/49
Shipping cask weight (metric tons)	8.9	8.9	40
Designation of railcars/ number of shipping casks per one car	TK-4 or TK-7/4 casks per car	TK-4 or TK-7/4 casks per car	TK-VG-18/3 casks per car
Number of casks per train/ number of fuel assemblies per shipment	18 cars/504 fuel assemblies	18 cars/504 fuel assemblies	4-8 cars/588 to 1,176 fuel assemblies

SOURCE: O. Bukharin, "Nuclear Fuel Management in the Russian Navy," unpublished contractor paper prepared for Office of Technology Assessment, U.S. Congress, Washington, DC, November 1994.

cient to make two trains. However, the number of corresponding railcars is sufficient for only one train.

The Military Industrial Commission, the defense planning arm of the Soviet government, had directed the Navy to start using new casks in 1983. The Navy, however, did not assign these plans high priority. Subsequently, the start-up was rescheduled and failed in 1985, 1988, and 1990. The principal technical problems of transition relate to the need for 1) new spent fuel and cask handling equipment, and 2) upgrade of the local road and railway networks (because TUK-18 casks are significantly larger and heavier than TUK-11 and TUK-12 casks).

These problems were overcome at the Northern Fleet shipyard, Severodvinsk: the first consignment of spent fuel in TUK-18 casks was sent to Mayak in May 1994 by train. TUK-18 casks were also used in the fall of 1994 to ship spent fuel from a shutdown reactor of the naval training facility at Paldiski (Estonia).

By the beginning of 1995, new fuel handling equipment was installed and tested with non-nuclear substitute casks aboard the MSC ship *Lotta.* The first train with spent fuel (which also carried some spent fuel from the Navy) departed from Atomflot for Mayak in March 1995. A total of five shipments are planned from Murmansk by MSC in 1995.

MSC's management has proposed that the company could become a central fuel transfer point in the North, which would serve both the nuclear icebreakers and the Northern Naval Fleet. According to the proposed scheme, submarine fuel would be transferred from the Navy's service ships to the *Lotta* prior to reloading in TUK-18 shipping casks. Because MSC believes that its company has a well developed technological and transportation infrastructure, competent personnel, and a valid operating license, consolidation of all marine nuclear fuel transfer operations would help to avoid duplication of facilities, increase the rate of shipments, and improve the safety of fuel reloading operations.

Implementation of this plan, however, might be impeded by the Zr-U fuel problem. Zr-U fuel cannot be reprocessed using existing facilities and practices in Russia. Currently, the spent fuel has to be stored aboard the service ships, *Lotta* and *Imandra*. The fuel (13 cores total) would fill most of the storage capacity of the two ships and limit MSC's ability to serve as a spent fuel transfer point. (The ships have a combined storage capacity of 20 reactor cores of spent fuel. Of these, a space for three cores must be reserved for freshly discharged fuel.) MSC's management proposes to resolve this problem by moving Zr-U fuel to new land-based storage facilities. The fuel would be placed in dry storage in multiple-purpose casks that would be installed at the Atomflot base. The casks could also accommodate damaged fuel from the *Lepse*. MSC, however, needs outside funding and/or equipment to implement this plan.

The situation in the Pacific is more serious. The last shipment of spent fuel from the Shkotovo waste site took place in 1993. As of beginning 1995, new fuel handling equipment was installed at the fuel storage facility at the Shkotovo waste site, and similar work has been started at the rail terminal. There is, however, the need to upgrade several kilometers of railway connecting the base to the central railway system and to complete upgrading of the road between the storage facility and the rail terminal.[22] These seemingly simple construction projects might be difficult to implement because of lack of funding. The Navy is also considering an alternative that would involve sending spent fuel by sea to the shipyard Zvezda, which would serve as a rail terminal for shipments to Mayak. The poor technical condition of the piers at Zvezda and the lack of funding in the Navy to pay the shipyard for fuel transfer operations may complicate the implementation of this plan.[23] If, however, the Navy cannot resolve the problem of shipments, a new interim storage facility would have to be built.[24]

The problem of shipments is compounded by the increasing costs of reprocessing spent fuel. In 1994, Mayak increased the costs of reprocessing from $500,000 to $1.5 million (1.5 billion to 7 billion rubles) per shipment (1.5 to 2 reactor cores or a few hundred kilograms of heavy metals). The increase was caused by financial problems in the nuclear industry, increases in federal taxes, and inflation.

Disposition of Spent Fuel

In Russia, naval spent fuel is normally reprocessed at the RT-1 chemical separation plant at Mayak in the Urals. The Mayak complex was brought into operation in 1949 to produce plutonium and, later, tritium for nuclear weapons. During the period 1959–60, Mayak and the Institute of Inorganic Materials (Moscow) began research on reprocessing of irradiated highly enriched uranium (HEU) fuel such as that used in the nuclear fleet. The research resulted in a technology to reprocess naval fuels, and a corresponding production line was brought into operation in 1976. It was the first production line of the RT-1 reprocessing plant.[25]

At present, the reprocessing complex includes three lines for processing fuel from commercial reactors (MTM models VVER-440,[26] BN-350/600) and from naval, research, and HEU-fueled reactors. In addition to the reprocessing lines, the complex includes facilities for short-term storage of spent fuel, waste storage and treatment facili-

22 Approximately 1.5 kilometers out of 3.5 kilometers of road have been constructed.

23 The Navy already has a large debt to the Zvezda shipyard.

24 The estimated time to construct a storage facility is six months.

25 In 1978, the RT-1 plant began reprocessing of spent fuel of model name VVER-440 reactors.

26 A Russian acronym: VVER=vodo-vodyanoy energeticheskiy reaktor (water (-moderated and -cooled) power reactor). The nameplate capacity of the MTM (MINTYAZHMASH) model VVER-440 line is 400 metric tons per year of VVER-440 fuel. The historic average throughput is 200 metric tons per year. Recently, however, the plant operated at 25 to 30 percent of its capacity. Reprocessing of VVER-440 fuel from Finland and Eastern Europe is the principal source of income for the Mayak complex.

ties, storage facilities for recovered plutonium and uranium, and other support facilities.[27]

The Mayak facility uses a system designed to reprocess standard uranium-aluminum naval reactor fuels. The facility previously had the capacity to process four to five reactor cores of spent naval fuel per year. Mayak can now process 12 to 15 metric tons of heavy metal (MTHM) per year. This corresponds to 24 to 30 reactor cores per year. At the current size of the fleet, normal fleet operations of the Navy and MSC should not require reprocessing more than about 10 to 20 cores per year. Thus, sufficient capacity exists for reprocessing additional fuel from decommissioned submarines as soon as the pace of dismantlement operations increases.

Mayak, however, cannot presently reprocess Zr-U fuel and damaged (or failed) fuels with its current system.[28] One problem with Zr-U alloy fuels is associated with the difficulty of dissolving them in nitric acid. The Institute of Inorganic Materials in Moscow has been researching several technologies to resolve this problem. A preferred method involving thermal treatment of the Zr-U fuel has been identified. However, MINATOM has not been able to secure funding for construction of a pilot facility at the RT-1 plant in Mayak. In the interim, MSC is pushing for the implementation of a plan to move all Zr-U fuel off its service ships into a land-based storage facility. The fuel would be housed in dry storage casks that would safely contain the fuel for dozens of years until suitable processing facilities, or long-term storage, can be arranged.

Potential for U.S.-Russian Cooperation in Spent Fuel Management

OTA sponsored a workshop in January 1995 with Russian and U.S. expert participants to discuss problems with spent fuel management in both countries. One outcome was the suggestion that cooperative projects might be useful and could lead to a number of mutual benefits. Addressing the many problems related to naval reactor fuel management is of major importance from the viewpoint of environmental cleanup, prevention of potentially serious accidents involving spent fuel, and progress of the submarine decommissioning program. Some factors are important to the United States as well as Russia; however, direct technical assistance to Russia has limitations. Other countries in Europe, especially Norway, and Japan are also interested in cooperative work to solve these problems. Assistance programs are difficult to manage and ensure that support ends up where it is most needed. Also, certain assistance efforts are complicated by the military nature of nuclear naval activities.

Box 4-11 describes some possible steps that could be introduced to address the above problems. Most of these are recognized by Russian experts and others as critical and necessary. The problem with spent fuel and radioactive waste in the Russian Navy is not new. (Even with the high rate of defueling/refueling in the late 1980s and the supposedly low rate of fuel shipment, it has taken several years to accumulate approximately 120 reactor cores currently in storage in the Navy and MSC.) The Navy had plans to modernize its waste and spent fuel management facilities back in the 1980s. Later, in the early 1990s, the problem was addressed in several major reports and programs. These documents call for development of a general concept of spent fuel management, construction of spent fuel handling equipment and fuel transfer bases, use of new shipping casks, development of technologies to dispose of nonstandard fuels and damaged reactor cores, work on long-term storage of spent fuel and geologic disposal of radioactive waste, and development of a special training center (10). Resolutions have been passed and plans have been developed on both regional and site levels

[27] Mayak has a 400-metric ton wet storage facility for VVER-440 fuel; a 2,000-metric ton interim storage facility is about 70 percent complete (65).

[28] Reprocessing of fuel assemblies with surface contamination is prohibited to avoid contamination of the production line.

BOX 4-11: Possible Steps for Improving Spent Fuel Management and Reducing Accident Risks

1. In the area of refueling and spent fuel storage:

- Procurement of new refueling equipment (e.g., PM-type service ships)
- Characterization of stored fuel and storage facilities (amounts, types, and condition of fuel, and status of available storage facilities) and safety upgrades at the existing facilities
- Analysis of options for and construction of interim storage facilities (if needed)[a]
- Development of a regulatory framework determining safety criteria for safe storage of spent naval fuel (how long and under what conditions storage of spent fuel is safe)
- Defueling of deactivated submarines if fuel or submarine conditions are unsatisfactory, and development of techniques for safe storage and monitoring of fuel when defueling can be postponed
- Transfer of the *Lepse* to a land-based facility
- Development of plans to decontaminate and dispose of contaminated storage facilities, the *Lepse,* and facilities with damaged fuel

These measures could be coordinated with a general concept of fuel and radioactive waste management to include the disposition of nonstandard, damaged, and failed fuels.

2. In the area of spent fuel shipments (if needed):

- Installation of equipment to work with TUK-18 casks in the north and in the Pacific
- Upgrades of the local transportation infrastructures

3. In the area of disposition of spent fuel

4. Other necessary factors include sufficient funding, clear division of institutional responsibilities, and improvements in personnel training and human resource management.

[a] Some Russian experts are concerned that additional facilities may result in a future decontamination and decommissioning problem. These experts believe that any available funds should be spent to carry out the standard approach (shipping spent fuel to Mayak and reprocessing). Multipurpose spent-fuel casks may answer some of these concerns should the storage situation become critical.

SOURCE: O. Bukharin, “Nuclear Fuel Management in the Russian Navy,” Staff Paper prepared for OTA, November 1994.

as well.[29] MINATOM, as a lead agency, has contracted various institutions and agencies to do the work. However, continuing problems with funding have largely stalled the progress.

The OTA workshop, thus, sought to identify areas in which cooperative work could be started soon, would offer clear mutual benefits, and could be supported by general agreement that its further pursuit would be worthwhile.

1. With regard to management of damaged spent fuel where technologies and systems are not currently in place, it is clear that damaged fuel is a major technological and management issue. In this regard, *a vulnerability assessment could be conducted to determine priorities with respect to off-loading damaged fuel from Russian submarines, surface ships, and fuel service ships.* Similar recent efforts regarding the problem of spent fuel include the identification of a critical situation aboard the service ship *Lepse* at Atomflot. This ship has damaged fuel stored that has been in place for up to 28 years. One of its two compartments, which contains seriously damaged spent fuel, has been filled with concrete, thus

[29] The following measures are planned at the Severodvinsk site to improve spent fuel management operations: 1) to upgrade refueling facilities at Sevmash, Sever, and Naval Repair Yard 412 (1993/94); 2) to develop procedures and a system of regulations for the removal of reactor core from submarines that are decommissioned at Severodvinsk; 3) to upgrade the transportation system at the naval base Belomorskaya; 4) to upgrade the railway system at the Belomorskaya naval base (48), the Sevmash site, and the 1944 Severodvinsk-Isagorka rail link; 5) to build new storage facilities; and 6) to build new service ships (6,48).

making the fuel assemblies very difficult to extract.

2. It may also be useful to investigate *technologies* (some of which are available in the United States) *to assess the status of damaged fuel* (i.e., corrosion and potential for criticality). Remote sensing technologies (e.g., mini-cameras and remote techniques) could be useful for the inspection of damaged fuel—an approach commonly used in the United States but apparently not readily available within the Russian nuclear fleet.
3. It would be constructive to develop *a case study and risk analysis of fuel management technologies using the service ship Lepse* (a service ship used for the nuclear icebreaker fleet that contains seriously damaged spent fuel). The *Lepse* is a commercial, not a defense, vessel; therefore, it would be easier for an international group to work on than a Navy submarine.
4. Another possibly useful collaborative project concerns *technologies that are needed to remove, off-load, and condition damaged fuel for local storage, for transport to a central storage facility, or for transport to a site for reprocessing*. Clearly, a decision will have to be made as to which option is preferred for matching the conditioning process to the intended fate of the spent fuel. On this subject, the United States could offer some lessons learned from its research on Three Mile Island to provide feasible conditioning options for the Russians to consider.
5. Both Russia and the United States could benefit from *an analysis of the commercial availability of dry storage and transportation technologies that could handle damaged and nonstandard fuel*. U.S. industry has examples of such systems and recently related applications. Mutual identification and development of these technologies would likely benefit both countries. Multipurpose casks for dry storage and shipment developed in the West are of particular interest to Russia.

Management of Liquid and Solid Radioactive Waste from the Nuclear Fleet

In addition to spent fuel management, other radioactive waste management problems from the Russian nuclear fleet are evident. As stated in the Yablokov report, past practices of the fSU's nuclear fleet resulted in direct at-sea discharges of low-level liquid radioactive waste (LRW). In the report, general areas of liquid waste disposal are identified in the Barents Sea in the north and the Sea of Japan, the Sea of Okhotsk, and the North Pacific Ocean in the east (23).

Recent reports state that the Northern Fleet stopped discharging LRW into the Arctic seas in 1992 (23). In the far east, an instance of liquid waste dumping occurred in October 1993, but no further discharges have been documented. In the north, two treatment plants for LRW were built at Zvezdochka (shipyard in Severodvinsk) and Sevmash (a Navy base) in the 1960s but never used and are now obsolete. At Sevmash there are five floating tanks for Northern Fleet LRW, each with a capacity of 19 to 24 m^3.

Also in the north, at Atomflot—Murmansk Shipping Company's repair, maintenance, and wastewater treatment facility 2 km north of Murmansk—LRW (primarily from icebreakers) is treated to remove cesium-137 (Cs-137) and strontium-90 (Sr-90), so that the effluent can be discharged to the Murmansk Fjord. Since 1990, a two-stage absorption system has been used with a capacity of 1 m^3 per hour and a yearly capacity of 1,200 m3 (4).

Although this treatment facility is primarily for icebreaker waste, it is the only facility available to also treat LRW from naval reactors. MSC has treated all of its LRW but cannot handle the backlog (or the amount generated annually) by submarines in the Northern Fleet. Atomflot says that it has the technical infrastructure to play a critical role in managing LRW on a regional scale. As a stopgap measure, the Northern Fleet uses two service ships to store its LRW.

Planned Liquid Waste Treatment in the North

Plans for a new treatment facility at the Atomflot complex have been under development for the past few years. The facility design currently proposed is based on an evaporation technology developed by the Institute of Chemical Processing Technology in Ekaterinburg and the Kurchatov Institute in Moscow. The current proposal would increase the capacity of LRW that could be handled to 5,000 m^3 per year. The new facility would be designed to handle three types of liquid waste: primary loop coolant from pressurized water reactors (PWRs), decontamination solutions, and salt water generated by Russian naval reactors. The LRW treatment capacity would handle both the icebreaker fleet and the Northern Fleet's needs (Murmansk and Arkhangel'sk Oblasts). The design of this expanded facility is now under way with assistance from both the United States and Norway. Its construction is planned to begin in late 1995.

The Russians had planned a new facility to handle the different types of LRW from submarines and icebreakers. It appears that the current design cannot process large quantities of the submarine waste, which contains salt water. The MSC now plans to build its new facility in two phases. The second phase (currently funded only by MSC) would extend the capacity from 5,000 to 8,000 m^3 a year (an additional 3,000 m^3). MSC plans to launch a commercial project with IVO International of Finland. This project would involve the use of a technology developed to remove Cs-137 from the primary loop coolant in the naval training reactor at Paldiski, Estonia. The facility would be upgraded and installed on the tanker *Serebryanka*. The capacity of the upgraded system is estimated as 1,000 to 2,000 cubic meters per year. Project cost is estimated at about $1 million. The combined output of the two facilities would handle all LRW generated from ship operations as well as a significant amount (several thousand cubic meters annually) generated in the submarine dismantlement process.

Since Russia has not been able to provide the necessary funds for the expansion of this facility, to date, the United States' and Norway's proposed cooperative effort to fund the expansion has received considerable attention over the past year. The Murmansk Initiative, as it is called, has involved technical exchanges, meetings, expert site visits, and other activities in 1994 and 1995. A facility expansion concept paper was prepared, and an engineering design has been funded. A discussion of the U.S.-Norwegian-Russian initiative can be found in chapter 5. This effort is one of the first examples of international cooperative work directed toward the prevention of further radioactive waste dumping in the Arctic.

Planned Liquid Waste Treatment in the Far East

Liquid radioactive waste treatment and storage capabilities are also in dire need of upgrading and improvement to service Russia's Far Eastern nuclear fleet. In 1993, Russia and Japan began a bilateral cooperative project to address this need. They developed a design and implementation plan for a new liquid waste treatment facility. An international tender was issued for the facility in 1994, and bids were due in late 1995. Russia has also undertaken interim measures to reduce pressures on sea dumping. Thus far, the United States has not participated in support for this facility as it has for the one at Murmansk (37).

■ Solid Low-Level and Intermediate-Level Radioactive Waste

Solid waste is generated during the replacement of fuel assemblies on icebreaker reactors, from repairs in the reactor section, and in the replacement of cooling water filters, cables, and gaskets. It is also generated from processing waste related to the storage of fuel assemblies. Contaminated clothes and work equipment are also part of the waste stream. Of the waste generated, 70 percent is low-level, 25 percent is intermediate-level, and 5 percent is high-level radioactive waste (48). Until 1986, all low- and intermediate-level solid waste from nuclear vessels was dumped into the sea. Since that time, solid waste has been stored, in some cases treated (e.g., incinerated), and in some cases disposed.

For example, at some sites in the north, radioactive waste is currently stored in containers placed side-by-side in a concrete bunker. Once the bunker is filled, it is sealed and covered. The largest storage facility for solid waste has reached 85 percent of its capacity. Large items that cannot fit easily into containers (reactor parts, cooling pipes, control instruments, and equipment employed in replacing used fuel assemblies) are placed on the ground without any protection or safeguards against drainage into the sea (48).

Given the range of activities taking place in and around the Arctic Sea and the apparent lack of secured, monitored storage, there appears to be a need for a regional depot to store low- and intermediate-level radioactive waste. Similar needs exist in the Far East.

A number of waste treatment facilities are in place. There is an incinerator at Atomflot for low- and intermediate-level waste. The waste volume is reduced 80 percent by this incinerator. The waste gases are filtered, and the ashes and filters are stored in containers (48). Some solid radioactive waste mainly from decommissioned submarines is also being incinerated at a naval facility in the north. Incinerator gases are controlled and led through special filters. When the radioactivity of the gases is too high, the facility shuts down—a frequent occurrence. Facility operation appears to be erratic; the facility reportedly runs for only one month a year due to filtration system overload and system shutdown.

There are also discharges of radioactive gases in connection with repairs at reactors and replacement of fuel assemblies. Such is the case at Severodvinsk where the annual discharge of such gases is estimated to be up to 10,000 m^3 from the labs and from storage of used fuel assemblies (48).

Russian sources have listed the following steps as necessary to manage waste generated in the Murmansk and Arkhangel'sk Oblasts: (4)

- develop new storage facilities,
- install preliminary radioactive waste treatment equipment at the point of waste generation,
- implement waste minimization and decontamination methods,
- develop safe transport facilities that meet international standards,
- develop a complex for radioactive waste treatment at Atomflot,
- develop solid waste supercompaction (1,500-2,000 metric tons of force) instead of the currently used incineration of lower-pressure (100 tons of force) compaction methods,
- construct a specialized ship for transporting solid radioactive waste packages to their final repository, and
- construct a radioactive waste repository for solid wastes in permafrost in Novaya Zemlya.

RUSSIAN NUCLEAR POWER PLANTS—SAFETY CONCERNS AND RISK REDUCTION EFFORTS

Background

Since the major nuclear reactor accident at Chernobyl, many nations have taken actions to help improve safety and reduce the risk of future accidents in all states of the former Soviet Union. Specific activities in Russia, discussed in this section, deserve particular attention in the context of preventing future radioactive contamination in the Arctic since Chernobyl releases are among the most widespread contaminants measured today throughout the general region.

Russia has 29 nuclear power units at nine reactor sites (see figure 4-4 for reactor locations).[30] In 1993, with these reactors operating at 65 percent capacity, they provided 12.5 percent of the electricity produced in the country.[31] There are two main reactor types in Russia: the

[30] Note, however, that the map lists only 24 reactors since it does not show either the four reactors at Bilibino or the one at Beloyarsk.

[31] In the United States in 1993, net electricity generated from nuclear power generating units was 21.2 percent of net electricity generated from utilities (63). For a discussion of older nuclear power plants in the United States (60).

RBMK and the VVER.[32] Box 4-12 and table 4-9 describe the types and locations of Russian power reactors. The Chernobyl reactor 4 that exploded in April 1986 in Ukraine was an RBMK reactor, and 11 of this type are now operating in Russia. The RBMK is a graphite-moderated, light-water-cooled reactor. Spent fuel from these reactors is replaced while the reactor is in operation, unlike PWRs, which must be shut down before refueling takes place. Experts outside Russia have criticized the RBMK design, especially since the Chernobyl accident, and have proposed several remedies ranging from safety improvements in existing reactors to substitution of new reactors with different designs, to outright replacement with other fuel sources.[33]

It is difficult to draw firm conclusions about the safety levels of all Russian reactors in general. Some have argued that Russian reactors are more geared toward prevention than reaction to a possible accident. For example, the higher water inventory in the VVER reactors, compared to Western-design PWRs, means that the heat-up process following an accident in which replenishment of makeup water is not available allows more time for corrective measures to be taken before possible damage to the fuel. Therefore, the need for containment and other postaccident mechanisms becomes somewhat compensated (3). However, this design advantage does not offset the need for improvements in Russian nuclear power plants (NPPs) suggested by many international experts. These include new monitoring and safety procedures that comply with international standards, reliable operating systems, well-trained operators, and sufficient funding for maintenance and spare parts.

Very few probabilistic risk assessments have been done to date and made available to the West for Russian reactors; thus, accident risk claims have not been established quantitatively. The Nuclear Regulatory Commission (NRC) hopes to convince Russia of the need to conduct such assessments. Another complicating factor in assessing the safety of Russian reactors is the fact that after January 1, 1993, the flow of information on plant design and accidents at these plants effectively dried up. Although the Soviet Union did sign certain international reporting conventions, the nations of the former Soviet Union effectively ceased making international accident reports in early 1993. When an event occurs, such reports are usually made to the Organization for Economic Cooperation and Development (OECD)'s Nuclear Energy Agency or to the International Atomic Energy Agency (IAEA), which rates and analyzes the incident (52).

Evaluations of U.S. efforts to improve the current conditions of reactor safety in Russia vary. A Gore-Chernomyrdin Commission (GCC) Nuclear Energy Committee report, the product of the December 15–16, 1994, GCC meetings, recognized these efforts, outlined in a December 1993 agreement, as unsuccessful. The December 1993 agreement was entitled, "On Raising Operational Safety, on Measures to Lower the Risk and on Norms of Nuclear Reactor Safety with Respect to Civilian Nuclear Power Plants of Russia." This agreement sought to facilitate cooperation under the Lisbon Initiative.[34] However, at the December 1994 GCC meetings, Russia accepted U.S. explanations for failure to complete projects planned for 1994 (9,20).

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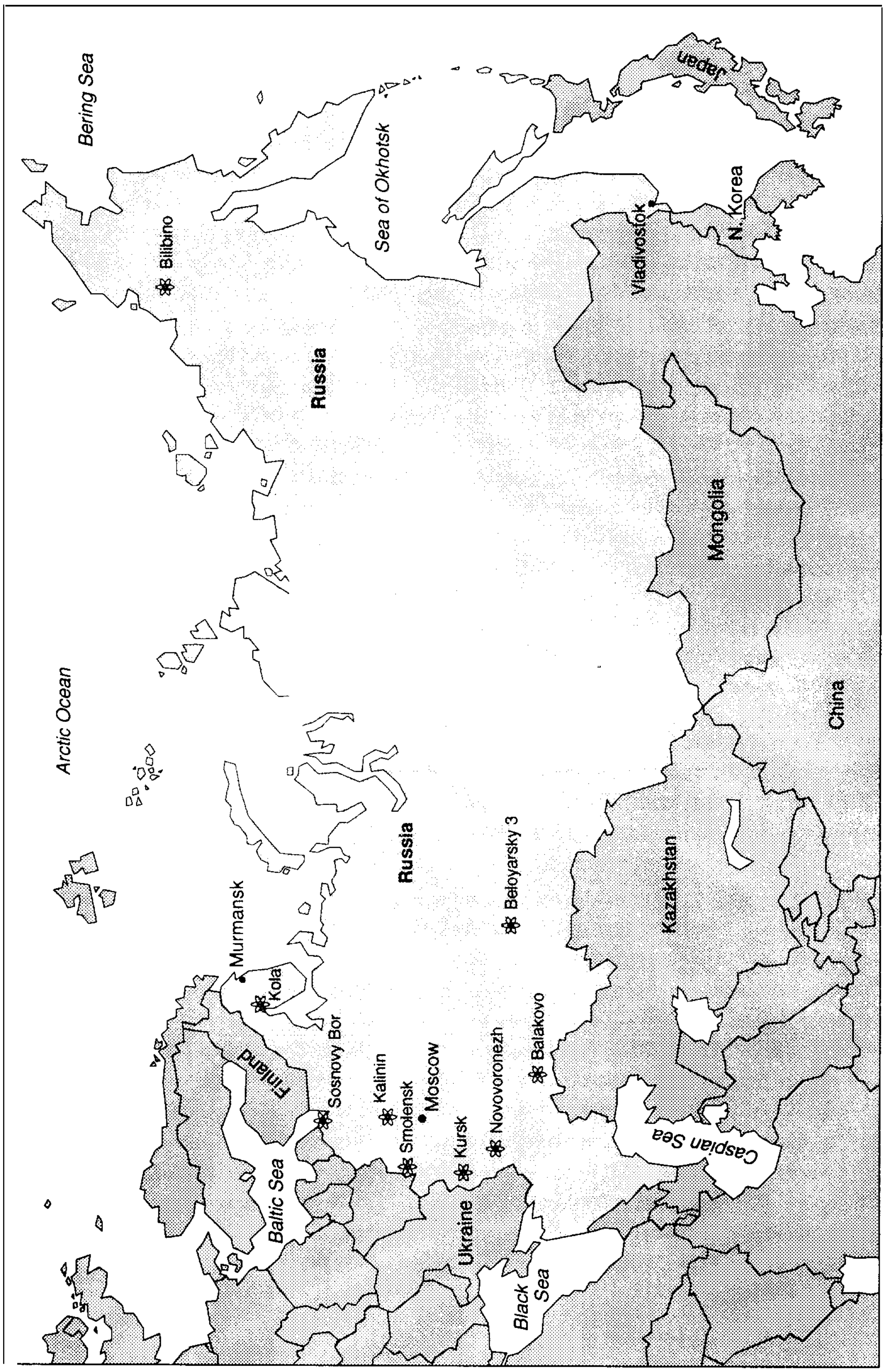
[32] A Russian acronym: RBMK=reaktor bol'shoy moshchnosti kipyashchiy (large-capacity boiling (-water) reactor).

[33] The two main safety concerns about the RBMK are: 1) core neutronics, or nuclear reactions in the core and 2) hydraulics of the pressure tubes. With regard to core neutronics, the RBMK has a positive void coefficient, which means that reactions speed up when water is lost from the core, for example, through excessive boiling or a loss-of-coolant accident. This happens because water serves to absorb neutrons; therefore, when water is lost, the number of neutrons increases, thereby speeding up the chain reaction. (Neutrons promote fission by hitting a uranium atom and causing it to split.) At Chernobyl unit 4 in April 1986, the chain reaction multiplied rapidly, generating high temperatures that caused an explosion. The second main concern, hydraulics of the pressure tubes, has to do with the possibility of fuel channel rupture. When reactivity speeds up, there is the possibility that several tubes might rupture simultaneously and pressure in the cavity below the reactor cover might increase enough to lift the head off, causing all the tubes to break and lifting out the control rods—a scenario that occurred at Chernobyl.

[34] The Lisbon Initiative refers to the current U.S. bilateral assistance program with the former Soviet Union in the area of nuclear reactor safety, which is discussed later in this chapter.



Source: Office of Technology Assessment, 1995.

BOX 4-12: Nuclear Power Reactors in Russia

Currently, Russia operates 11 RBMKs[1] at three sites: four near St. Petersburg, four at Kursk (south of Moscow), and three at Smolensk (southwest of Moscow). The St. Petersburg units, located in Sosnovy Bor, St. Petersburg Oblast, are the only ones out of the 29 operating units in Russia that are run by a separate utility company, the Leningrad Nuclear Power Plant Utility. The Ministry of Atomic Energy (MINATOM) operates all other power plants through an organization known as the Rosenergoatom Consortium. Each of the 11 RBMK units has a capacity of 925 net MW_e (megawatts of electricity). The first St. Petersburg unit came online in December 1973, and the last in February of 1981. The earliest Kursk unit dates from December 1976, and the latest from December 1985. The Smolensk units are somewhat newer, dating from December 1982 to January 1990.

The EPG-6 is a reactor type similar to the RBMK. It too is graphite moderated and boiling water cooled. The four existing reactors of this type are found at Bilibino on the Chukchi Peninsula in the Russian Oblast of Magadan, which is about 100 miles north of the Arctic Circle in the Russian Far East. Each of the Bilibino units has a capacity of 11 net MW_e. Unit A at Bilibino began operation in January 1974, unit B in December 1974, Unit C in December 1975, and Unit D in December 1976.

The other main type of reactor in the former Soviet Union is the VVER,[2] which is a pressurized water reactor (PWR) design, the main reactor type in the West. It is water moderated and cooled. The oldest version of this reactor is the VVER 440/230, followed by the 440/213, both of which produce 440 MW_e of electricity. The oldest of the VVER reactors, the 440/230, like the RBMK, is considered by many Western observers to have safety problems. It lacks an emergency core cooling system to prevent the core from melting after a loss-of-coolant accident. Moreover, the reactor vessel is vulnerable to radiation-induced embrittlement, which increases the risk of fracture in the vessel. It also lacks containment vessels to prevent the escape of radioactive materials after severe accidents. It should be noted, however, that the model 230 has several positive features. Since it has a large water inventory and low power density, it can more easily ride out problems such as a “station blackout” when there is a loss of the power needed to run pumps that cool the core. The model 230 also has an “accident localization system” to condense steam and reduce the release of radiation after an incident in which most pipes in the reactor system break, thereby mitigating the danger inherent in a design that has no containment vessel.

The VVER 440/213, a newer model, includes an emergency core cooling system, an improved reactor vessel, and an improved accident localization system. This model, however, still lacks full containment (except in the case of those models sent to Finland and Cuba).

The Kola NPP, with four reactors, is located in the Murmansk region above the Arctic Circle near the northeastern border of Norway. Two of these reactors are the oldest generation units, VVER 440/230s. They came online in June 1973 and December 1974, respectively. The other two units are VVER 440/213 units, which began operation in March 1981 and October 1984, respectively. At the end of 1994, only two of the Kola power units were operational, and prospects are problematic for continued operation of the remaining units because of difficulties in collecting fees owed by Murmansk Oblast industries.

The newest generation of VVER reactors in Russia is the VVER-1000, which is most like a Western nuclear power station. It runs at 1,000 MW_e, and its design includes a full containment vessel and rapid-acting scram systems. Experts believe that this design could approximate Western safety standards, given some modifications, such as increased fire protection and improved protection of critical instrumentation and control circuits.

(continued)

BOX 4-12: Nuclear Power Reactors in Russia (Cont'd.)

Novovoronezh NPP, located in southwestern Russia, has two 440/230 reactors, which began operation in December 1971 and 1972, respectively, and one VVER-1000, which began operation in May 1980. Kalinin NPP, located northwest of Moscow, has two VVER-1000 units. Unit 1 came online in May 1984 and unit 2 in December 1986. Balakovo NPP, which is located along the Volga River southeast of Moscow, has four VVER-1000 units; the first began operation in December 1985, and the last, Balakovo 4, became commercially operable in April 1993. Balakovo 4 is the newest of all Russia's reactors and the first one built since 1990.

Only one other type of reactor, the BN-600, a fast breeder reactor, is operating in Russia. It is known as "Beloyarsky 3" and is located in the Ural Mountain area, about 900 miles east of Moscow. It has a capacity of 560 net MW_e and has been in operation since April 1980.

[1] RBMK = Reaktor bol'shoy moshchnosti kipyashchiy (large-capacity boiling [-water] reactor).
[2] VVER = Vodo-vodyanoy energeticheskiy reaktor (water [-moderated and -cooled] power reactor).

SOURCES: U.S. Department of Energy, Energy Information Administration, *EIA World Nuclear Outlook, 1994*, DOE/EIA-0436(94) (Washington, DC: US Government Printing Office, December 1994); U.S. Congress, Office of Technology Assessment, *Fueling Reform: Energy Technologies for the Former East Bloc*, OTA-ETI-599 (Washington, DC: U.S. Government Printing Office, July 1994); U.S. Congress, General Accounting Office, *Nuclear Safety: International Assistance Efforts to Make Soviet-Designed Reactors Safer*, GAO/RCED-94-234 (Washington, DC: U.S. Government Printing Office, September 1994); "Funding Crisis Could Cause Nuclear Station Shutdown," Moscow Ostankino Television, First Channel Network, in FBIS Report/Central Eurasia (FBIS-SOV-94-227) Nov. 25, 1994, p. 35.

Russian officials have stated that the United States unilaterally determines priorities, and pays too much attention to analysis and not enough to practical solutions. As an example, they point to 1994 when no supplies or equipment were sent, although some had been sent in 1993 (9). However, the Chairman of GOSATOMNADZOR told a September 1993 meeting of Group of Twenty-Four (G-24) representatives that the bilateral assistance implemented in the regulatory field was timely and effective, compared with other Western assistance (58). One possible reason that the NRC is actually ahead of schedule is that unlike the Department of Energy (DOE) and its contractors, NRC has not been hampered by liability problems (52).

One of the biggest impediments to the development of a safety culture in Russia lies in the human arena: the current low pay and low morale of plant employees work to undermine a concern for safety. Socioeconomics is a formidable consideration. The prospect of shutdown at a station such as Chernobyl in Ukraine, which is responsible for 7 percent of national energy production, carries with it the implication of social unrest, given the extensive loss of jobs (staff of 5,800) that would ensue. Also, in the former Soviet Union, nuclear power plants, like many workplaces there, are responsible for providing a host of social services for their employees. This makes their closure a much more painful and, potentially, more politically and economically destabilizing measure.

According to former NRC Chairman Ivan Selin, the three most important elements for shoring up a strong safety culture are as follows: 1) technical excellence and operational safety enforced by a tough, independent regulator, and supported by timely plant operator wage payments and payments to utilities for electricity produced; 2) a sound economic climate that allows for a sufficiently profitable nuclear program capable of underwriting first-rate training, maintenance, and equipment, and incorporates a new energy pricing mechanism to encourage energy conservation; and 3) solid organization and management, including high-quality staffing, training, and responsible leadership. He rec-

TABLE 4-9: Russian Nuclear Generating Units Operable as of December 31, 1994

Unit name	Location	Capacity (net MW_e)	Date of operation	Reactor type	Reactor model
Balakovo 1	Balakovo, Saratov	950	December 1985	PWR	VVER-1000
Balakovo 2		950	October 1987	PWR	VVER-1000
Balakovo 3		950	December 1988	PWR	VVER-1000
Balakovo 4		950	April 1993	PWR	VVER-1000
Beloyarsky 3	Zarechny, Sverdlovsk	560	April 1980	FBR	BN-600
Bilibino A	Bilibino, Chukotka	11	January 1974	LGR	EPG-6
Bilibino B		11	December 1974	LGR	EPG-6
Bilibino C		11	December 1975	LGR	EPG-6
Bilibino D		11	December 1976	LGR	EPG-6
Kalinin 1	Udomlya, Tver	950	May 1984	PWR	VVER-1000
Kalinin 2		950	December 1986	PWR	VVER-1000
Kola 1	Polyarniye Zori, Murmansk	411	June 1973	PWR	VVER-440/230
Kola 2		411	December 1974	PWR	VVER-440/230
Kola 3		411	March 1981	PWR	VVER-440/213
Kola 4		411	October 1984	PWR	VVER-440/213
Kursk 1[a]	Kurchatov, Kursk	925	December 1976	LGR	RBMK-1000
Kursk 2		925	January 1979	LGR	RBMK-1000
Kursk 3		925	October 1983	LGR	RBMK-1000
Kursk 4		925	December 1985	LGR	RBMK-1000
Leningrad 1[a]	Sosnovy Bor, St. Petersburg	925	December 1973	LGR	RBMK-1000
Leningrad 2[a]		925	July 1975	LGR	RBMK-1000
Leningrad 3		925	December 1979	LGR	RBMK-1000
Leningrad 4		925	February 1981	LGR	RBMK-1000
Novovoronezh 3	Novovoronezhsky, Voronezh	385	December 1971	PWR	VVER-440/230
Novovoronezh 4		385	December 1972	PWR	VVER-440/230
Novovoronezh 5		950	May 1980	PWR	VVER-1000
Smolensk 1	Desnogorsk, Smolensk	925	December 1982	LGR	RBMK-1000
Smolensk 2		925	May 1985	LGR	RBMK-1000
Smolensk 3		925	January 1990	LGR	RBMK-1000
Total: 29 units		**19,843**			

[a] Under reconstruction.

KEY: LGR=light-water-cooled, graphite-moderated; PWR=pressurized light-water-moderated and cooled; FBR=fast breeder reactor.

SOURCES: U.S. Department of Energy, Energy Information Administration, *EIA World Nuclear Outlook, 1994*, DOE/EIA-0436(94) (Washington, D.C.: U.S. Government Printing Office, December 1994); Gosatomnadzor, “Characteristics of the Status of Safety at Nuclear Power Plants in Russia (for 1994),” (Moscow, Russia: GAN, circa 1994).

ommends that Western assistance efforts be directed toward longer-term initiatives, such as ensuring adequate resources and sound institutional and management arrangements, rather than short-term approaches, such as technical fixes, operational improvements, and regulatory procedures (51,54). Other experts agree that with the volatile socioeconomic situation in Russia, assistance money might be wasted if it is used on technologies that the Russians are financially incapable of maintaining or regulating properly.

International Programs Addressing Reactor Safety

Group of Seven and Other Multilateral Efforts

The Group of Seven (G-7) summit in Munich in July 1992 was a seminal conference in the evolution of reactor safety. At that summit, participating countries designed an emergency action plan for the safety of Soviet-designed reactors. Operational improvements including near-term technical assistance and training are part of the plan, as are regulatory improvements. In response to suggestions made at the conference, donor countries conducted assessments on: 1) the feasibility of alternative energy sources and conservation practices, to allow for the replacement of the oldest and least safe plants; and 2) the potential for upgrading newer reactors to meet international safety norms.

The World Bank, the European Bank for Reconstruction and Development (EBRD), and the International Energy Agency (IEA) have been conducting these studies, which were completed recently. However, according to the Center for Strategic and International Studies' Congressional Study Group and Task Force on Nuclear Energy Safety Challenges in the Former Soviet Union, the studies provide neither detailed practical options on which to base U.S. policy nor convincing arguments that might persuade countries in the Newly Independent States (NIS) and Eastern Europe to shut down the riskiest reactors before their planned life spans are completed. Apparently, the G-7 and the authors of the studies themselves concur in this opinion (7).

International Convention on Nuclear Safety

Additional multilateral efforts include the International Convention on Nuclear Safety, an agreement that would urge shutdowns at nuclear power plants that do not meet certain safety standards. These are not detailed technical standards. Instead, the standards that the convention stipulates are general safety principles, including the establishment of a legislative framework on safety and an independent regulator; procedures to ensure continuous evaluation of the technical aspects of reactor safety (e.g., this would require countries to establish procedures to evaluate the effect of site selection on the environment and to ensure protection against radiation releases); and a safety management system (e.g., establishing a quality assurance program, training in safety, and emergency preparedness plans). Work on the convention began in 1991 in the wake of the dissolution of the Soviet Union. As of September 21, 1994, 40 nations had signed the convention including the United States, Russia, and Ukraine. With its signing by 40 nations, the agreement can now go before each nation's legislative body or parliament for ratification. The agreement calls on signers to submit an immediate report on all nuclear power facilities and, if necessary, to execute speedy improvements to upgrade the sites. The convention also sets up a framework for the review of a nation's atomic sites by other nations, with special provisions for such a request from neighboring countries, which may be concerned about the health of their populations and crops. The convention does not provide for an international enforcement mechanism and has no penalties for noncompliance, so as not to infringe on national sovereignty. As drafted, the convention designates IAEA as Secretariat to the meetings of involved countries (1,59).

There are several other multilateral programs whose goal is to promote nuclear safety within the former Soviet Union. Most are smaller and more specifically targeted than the above efforts.

The U.S. Nuclear Safety Assistance Program

The Joint Coordinating Committee for Civilian Nuclear Reactor Safety (JCCCNRS) is a cooperative exchange program between the United States and the Soviet Union, which was initiated in 1988. It was established in accordance with a Memorandum of Cooperation under the Agreement between the United States and the U.S.S.R. on Scientific and Technical Cooperation in the Field of Peaceful Uses of Atomic Energy (PUAEA)—an agreement signed in 1972. Not until the late 1970s, however, was the nuclear safety issue incorporated in the Peaceful Uses Agreement, and even then action on cooperation in nuclear safety was delayed due to the Soviet invasion of Afghanistan in 1979.

After the Chernobyl accident in 1986, renewed zeal was focused on the issue of nuclear safety within the framework of the PUAEA. On April 26, 1988, two years to the day after Chernobyl, the JCCCNRS was created under the Peaceful Uses Agreement. Russia and Ukraine have been formal successors to the U.S.S.R. on both the Peaceful Uses Agreement and the JCCCNRS. Representatives from both the atomic energy and the regulatory ministries in each country act as co-chairs of the JCCCNRS. Similarly, DOE and NRC are the co-chairs from the United States. Although the dissolution of the Soviet Union in late 1991 had little impact on the progress of activity under the JCCCNRS Memorandum of Cooperation, it did usher in new operational and regulatory organizations in the former Soviet Union and introduced economic problems with negative consequences for nuclear safety, including a lack of money for maintenance and shortages of spare parts.

A conference in May 1992 in Lisbon, Portugal, represented a turning point in U.S. nuclear safety assistance to the NIS. The U.S. program changed from a program of cooperative exchanges to one of specific, targeted assistance. Commonly called the Lisbon Initiative, the current U.S. nuclear safety assistance effort began as an outgrowth of JCCCNRS and has in many ways superseded JCCCNRS work. Nevertheless, JCCCNRS still exists and retains some of its original working groups.

The May 1992 Lisbon meeting and the corresponding U.S. commitments made at the G-7 conference in Munich in July 1992 are the basis for the current DOE-led program in nuclear safety assistance to the NIS, the Program for Improving the Safety of Soviet-Designed Reactors, under the International Nuclear Safety Program (INSP). INSP activities are conducted according to the guidance and policies of the State Department, the U.S. Agency for International Development (U.S. AID), and the Nuclear Regulatory Commission. All four agencies work together to achieve the objectives of the INSP, which are the following: 1) to strengthen operations and upgrade physical conditions at plants, 2) to promote a safety culture, and 3) to facilitate the development of a safety infrastructure.

In addition, at the Vancouver Summit in May 1993 the United States and Russia laid the groundwork for the U.S.-Russia Commission on Economic and Technological Cooperation, better known as the Gore-Chernomyrdin Commission. The first meeting of the GCC took place in Washington, D.C., in September 1993. At that meeting, Vice President Gore and Prime Minister Chernomyrdin agreed on a joint study on alternate sources of energy in Russia, which is being carried out by U.S. AID in close cooperation with the World Bank and other organizations. Also at that first GCC meeting, the Nuclear Safety Subcommittee, co-chaired by DOE and NRC for the United States and MINATOM and GAN for Russia, was formed.

Activities within the Department of Energy

The International Nuclear Safety Program is a Department of Energy effort to cooperate with partners in other countries to improve nuclear safety worldwide. Activities directed toward raising the level of safety at Soviet-designed nuclear power plants play a major role in this worldwide effort. The overall objectives of the Program for Improving the Safety of Soviet-Designed Reactors include the following: 1) to strengthen operation and upgrade physical conditions at plants, 2) to promote a safety culture, and 3) to facilitate the development of a safety infrastructure. The thrust of the program involves encouraging these countries to help themselves. Work under the program is organized according to the following major program elements:

1. *Management and Operations:* Major activities involve development and implementation of the following: emergency operating instructions (EOIs); practices and procedures for the safe conduct of plant operations; and training programs, including those based on the use of simulators, with training centers at the Balakovo Nuclear Power Plant in Russia and the Khmelnitsky Nuclear Power Plant in Ukraine. The program also seeks to improve emergency response capabilities through integration and through training and assistance in deficient areas.
2. *Engineering and Technology*: The focus is on the transfer of techniques, practices and procedures, and tools and equipment to upgrade plant safety. Training in the use of transferred items will also be provided to help countries help themselves in the future. Generally, when a hardware backfit is necessary for safety improvement, a single plant is selected for a "pilot demonstration" of the technology transfer. Under certain circumstances, however, (e.g., when insufficient economic incentives exist for the transfer of specific technologies), similar safety upgrade projects may be carried out at multiple plants. Upgrades in safety-related systems include fire safety, confinement, reactor protection, emergency power, and emergency feedwater systems. In pursuing upgrades in the safety-related systems of older reactors, caution is taken so as not to encourage continued operation of these reactors. The program element "engineering and technology" also encompasses the establishment of national technical standards. Examination of areas such as design control, technical and material specifications, nuclear equipment manufacturing, configuration management, and nondestructive testing methods will be performed to determine where practices should be changed to ensure sufficient levels of quality.
3. *Plant Safety Evaluation:* Safety evaluation is an area of the program receiving increasing emphasis (19). The idea is to develop the methodologies, techniques, and expertise necessary for safety analyses to be performed consistent with international standards. Plant-specific analyses will likely draw on more general studies that have already been completed by the IAEA. Priority of work will be decided with a view to furthering projects by the EBRD. Activities will include probabilistic risk assessments and assistance with the prioritization of future plant modernizations.
4. *Fuel Cycle Safety:* This element of the INSP Soviet-Designed Reactor Safety Program deals exclusively with Ukraine. The objective of the Fuel Cycle Safety Program is to address safety issues surrounding interim storage of spent fuel in Ukraine. Assistance and training to both Ukrainian power plant operators and regulators will include efforts toward the licensing of additional spent fuel storage capacity, the procurement and delivery of dry cask storage prototypes and related equipment for use at the Zaporozhye plant, and assistance as requested by Ukrainian regulators. Analysis and strategic planning regarding the adequacy and safety performance of spent fuel storage systems are fundamental to the program.
5. *Nuclear Safety Legislative and Regulatory Framework:* The major emphasis of this program element is on Russia. The focus is on the development of a legal framework that promotes the following: adherence to international nuclear safety and liability conventions and treaties; domestic indemnification for nuclear safety liability (domestic indemnification legislation would allow for broader use of Western safety technology); and establishment of strong, independent regulatory bodies. The program will encourage the habit of incorporating regulatory compliance at all stages of engineering and operations. It will also ensure that an appropriate regulatory framework exists to support other INSP project elements. Evaluation of the legislative and regulatory status in the host country will

take place in cooperation with the U.S.NRC program. Should improvements in the regulatory framework of the host country be deemed necessary, assistance will be provided to complement related ongoing NRC activities.

Activities within the Nuclear Regulatory Commission

The Nuclear Regulatory Commission programs, begun in October 1992 under the Lisbon Initiative assistance effort in Russia, include the following:

1. *Licensing Basis and Safety Analysis:* This involves training and technical assistance on NRC practices and processes for the licensing of nuclear power plants, research reactors, and other facilities involved in the use of radioactive materials. This program was the first-ranked priority project requested by the Russians and has witnessed nine teams of GAN representatives travel to the United States during 1993–94.
2. *Inspection Program Activities:* These provide training and technical assistance on the NRC inspection program. Four training team visits, two Russian teams to the United States and two U.S. teams to Russia, took place during 1993–94. Also, NRC officials participated in a joint pilot team inspection at a Russian plant.
3. *Creation of an Emergency Support Center:* Assistance is provided in establishing incident response programs. Again, team exchanges took place in both directions.
4. *Analytical Support Activities:* These assist in the implementation and application of analytical methodologies to the performance of safety analyses. NRC has solicited a contractor to provide technical support in the procurement and installation of engineering work stations. These will be useful for performing severe accident analyses, which employ U.S. computer codes that have been modified for the Russian nuclear power plants. A national laboratory has agreed to provide some analytical code training.
5. *Establishment of a Regulatory Training Program:* Assistance is provided in the establishment of a regulatory training program in Russia. Nine microcomputer systems, to be used for computer-based training, were delivered to Moscow in July 1993 and more are being sent. Also in July 1993, four GAN officials completed a three-week assignment at the NRC Technical Training Center (TTC), at which they learned about the training of NRC personnel. In August of that year, four more GAN officials spent two weeks at the facility learning about the use of training aids such as simulators and the use of equipment for developing and presenting course materials. Another contingent of GAN technical personnel visited TTC in November 1993. When further funding is available, implementation will begin on an agreement to acquire and deliver an analytical simulator, developed by a joint U.S.-Russian venture.
6. *Creation and Development of a Materials Control and Accounting System:* Not part of JCCCNRS, this program offers assistance in nuclear materials accounting and control under the Safe and Secure Dismantlement of Nuclear Weapons program.
7. *Fire Protection Support:* Technical assistance is provided in the development and review of fire protection inspection methodology and implementation of this methodology at Russian reactors. NRC developed a historical fire protection and postfire safe shutdown licensing analysis document for GAN use.[35] After the fire protection/safe shutdown licensing document, GAN specialists visited NRC and regional fire protection specialists to learn about regulations, licensing practices, and inspection methodologies in this area. Further work in this area has been requested by GAN.

[35] It should be noted, however, that MINATOM refuses to recognize the validity of GAN's licensing procedures. Enabling mechanisms are necessary to make licensing enforceable. Russian domestic legislation probably would be necessary in this area to resolve these differences (52).

8. *Probabilistic Risk Assessment Study for the Kalinin VVER-1000 Power Station (Beta Project):* A risk assessment study on Kalinin is to be developed. A kickoff meeting between the primary Russian and U.S. participants was held in May 1994. The various phases envisioned for the project include the following: Phase 1—Project Organization; Phase 2—Training, Procedures Guide Development, and Data Gathering; Phase 3—System Modeling and Accident Frequency Analysis; and Phase 4—Containment Performance. Statements of work have been done for the first three phases.
9. *Licensing and Inspection of Radioactive Materials:* Key GAN personnel are trained in health and safety issues relating to the licensing and inspection program at NRC for nonmilitary possession, use, and disposal of radioactive materials. This priority area involves on-the-job training in nuclear materials transport, the nuclear fuel cycle, spent fuel storage, nuclear waste programs, and radioisotope practices.
10. *Institutional Strengthening:* General support is provided to GAN in the following areas: document control management and computer utilization, electronic information communication, safety information publication, and the International Council of Nuclear Regulators (NRC agreed to investigate ways to underwrite GAN participation in council activities).

Nuclear Power Plants in the Arctic

The Bilibino Nuclear Power Plant

The two Russian nuclear power plants with potentially the greatest impact on the Alaskan environment are Bilibino in Chukotka Oblast in the Russian Far East and Kola in Murmansk Oblast. Bilibino is about 810 miles from Nome, Alaska; 1,250 miles from Fairbanks; and 1,860 miles from Juneau. Since Bilibino in the Russian Far East is a small-capacity station (each of the four units has a capacity of only 11 net MW_e) (megawatts of electricity), no DOE resources have been expended to assist in upgrading it. There is the possibility, however, that emergency response money will be directed toward this end in the future (55). However, NRC and GAN are cooperating on safety aspects of this facility. They are considering improvements in communication links between Bilibino and Moscow, in conjunction with an emergency support center at GAN headquarters in Moscow. Nuclear power plants in the United States make routine daily status reports to NRC, and NRC is working to establish a similar system in Russia, whereby the plants in Russia report to GAN in Moscow.

As mentioned above, the reactor design at Bilibino is EPG-6, graphite moderated and boiling water cooled, similar to the RBMK but with noteworthy differences. Comparisons to Chernobyl should be made cautiously. Fuel design and uranium enrichment differ between the two reactor types. These differences affect both the risk of an accident and its possible consequences. The possible consequences of an accident depend on the total inventory of fission products in the core at the time of an accident and the fraction and composition of the inventory that actually gets into the atmosphere. At any given time, Bilibino should have only about 1 percent of the total inventory of fission products in the Chernobyl reactor during the accident there in April 1986. Although little is known about the actual risk of accident at Bilibino, possible consequences of an accident, should one occur, could be estimated by using the knowledge available. Some researchers have made preliminary estimates of the consequences of an accident at Bilibino that indicate very low concentrations of radionuclides would be carried as far as Alaska.

All low-level waste is concentrated and stored onsite at Bilibino. High-level waste, including spent fuel, filters, and reactor components, is held onsite in stainless steel-lined concrete tanks. Fuel storage pools are closer to operating reactors than is advised in the United States.

A radiological emergency response plan exists for Bilibino. Unlike U.S. plans, this plan is based on actual postaccident measurements of a release rather than on plant conditions or dose projection models. As a result, prerelease notification of deteriorating plant conditions, which would be included in Alert, Site Area Emergency, or General Emergency reports in the United States, are not possible under the Bilibino emergency response system. The Bilibino plan's accident assessment categories differ from both IAEA International Nuclear Event Scale categories and the U.S. system of classification.[36] Therefore, some have recommended that U.S. officials seeking direct communications with Bilibino personnel and with civil defense (Emergency Situations Office)[37] officials should become familiar with the plan and its accident assessment categories, which are based on a wartime nuclear attack plan. Because of fundamental differences between United States and Russian emergency response philosophies, some have also recommended that a "tabletop" drill be carried out between Alaska and Chukotka. This would allow both sides to test communication links and make sure they understand each other.

In late June 1994, a four–day International Radiological Exercise (RADEX) was convened to test emergency response procedures. Three representatives from Bilibino and from the Chukotka Regional Government participated, as did other representatives from the Arctic Environmental Protection Strategy (AEPS) nations, various Native groups, and the International Atomic Energy Agency.[38] Also, the Office of Naval Research (ONR) is funding Emergency Response Collaboration with the Bilibino Region as one of the projects under its Arctic Nuclear Waste Assessment Project (ANWAP), which is funded by money from the Cooperative Threat Reduction Program. Under this program, in June 1994, Alaska hosted three Bilibino staff and a member of the Chukotka regional government for a visit that coincided with the RADEX tabletop exercise. In September 1994, the principal investigator for the Emergency Response Collaboration project under ANWAP, Mead Treadwell, then Commissioner of Alaska's Department of Environmental Conservation, met with officials of the Finnish Centre for Radiation and Nuclear Safety in Rovaniemi, Finland, and a conceptual agreement was reached on the development of further linkages in emergency response. Russian participation is responsible for about 25 percent of both the effort and the funds that have been expended on the Emergency Response Collaboration with the Bilibino Region project.

Under the current reporting system, accidents at Bilibino would be reported to Moscow, from Moscow to IAEA headquarters in Vienna, from Vienna to Washington, D.C., and from Washington to Alaska. Moreover, under the Convention on Early Notification of a Nuclear Accident, agreed to by the United States, the U.S.S.R., and other states in 1986, the criterion for notification is "radiological safety significance for another state," as understood by the originating state. Russian officials might reasonably argue that, given the small size of the Bilibino plant and its distance from the United States, even a severe accident there would not constitute "radiological safety significance" for another state and, therefore, would go unreported. Alaska is pushing for direct notification from Bilibino.

Improved radiation monitoring is, of course, integral to the detection and notification process. Also under ANWAP, efforts are under way to improve radiation monitoring. ONR support has made possible cooperation between the University of Alaska and the DOE Los Alamos National Laboratory in the installation of two atmospheric radiation monitors for winter capability testing. If these are successful, installation will be established at Bilibino, and personnel from the

[36] Bilibino does not use the IAEA scale, but the Russian Federation does use it when sending information to other countries and IAEA.

[37] Peacetime radiological emergency response capabilities may be shifting away from the Civil Defense Committee, since there is a reduced emphasis on civil defense with the end of the Cold War (57).

[38] AEPS was established in 1989 and consists of eight countries, including the United States, Canada, Denmark, Finland, Iceland, Norway, Russia, and Sweden. In 1991 in Rovaniemi, Finland, these countries agreed on a strategy that includes objectives and an action plan, calling for four implementing working groups, including the Emergency Prevention, Preparedness and Response Working Group, which was involved in the RADEX exercise.

Department of Environmental Conservation and the University of Alaska at Fairbanks will maintain the equipment.[39]

The Russians have announced some plans to expand power generation capacity at Bilibino to 120 MW_e, by replacing the four 11-MW_e reactors with three 40-MW_e reactors. One plan under study by MINATOM would involve construction of floating nuclear power plants similar in basic design to those used in Russia's nuclear-powered icebreakers. The floating plants would be built in a shipyard and towed to northern Siberian locations such as Bilibino. It is not clear whether or when funds would be available for these projects. The existing reactors have a 25-year design life, and the first one is scheduled for decommissioning in 2003. Plans for both decommissioning and expansion are due in 1998. A concern at the present time is that Bilibino is in an area of high seismic activity, and the reactor lacks containment. In June 1992, Y.G. Vishnevskiy, Chairman of the Russian State Nuclear Inspectorate (GAN) stated that:

> generating units of the Bilibino NPP completely fail safety rules and standards. They have outlived their original life and must be immediately shut down, especially since they are located in a seismic zone.[40]

Although the basic reactor design would remain the same in the proposed replacement systems, containment for each new reactor would be included in the changes. Prior to the expansion, installation of automatic monitoring equipment is planned for 1996. Russian authorities have also announced plans for waste management facilities at or near the plant site, but details are not clear. Bilibino management believes it would require at least $16 million to make all the modifications at the plant necessary to meet the most recent Russian power plant standards (57,63). However, despite the proposed improvements, Magadan officials fear that the quality of radiation control at Bilibino may be compromised for several reasons: 1) declining socioeconomic conditions have led many qualified specialists to leave Bilibino; and 2) the relatively recent separation of Chukotka from Magadan Oblast administration, and Chukotka authorities' refusal to accept the services of Magadan radiological labs, mean a reduction in access to, and regulation from, other facilities (57).

DOE's program for Bilibino, under the INSP, includes a project to develop a training center there. The project, which has been proposed for FY 1995, includes assistance to determine Bilibino's needs in terms of training and the delivery of training center equipment.

The Kola Nuclear Power Plant

The Kola plant is located near the northeastern border of Norway in Polyarnye Zori, Murmansk Oblast. Kola has two of the oldest-generation VVERs, the VVER 440/230, which has neither containment nor emergency core cooling. It also has two VVER 440/213s, which lack containment but do have systems for emergency core cooling. Kola is responsible for between 60 and 70 percent of the combined production of electricity (thermal and electrical) in Murmansk Oblast. Each reactor has one to two emergency stops per year on average. In 1992, there were 39 reported incidents, six of which were first-level incidents on the IAEA Event Scale and one of which was second-level. IAEA investigated the four Kola reactors in 1991 and determined that the chances of reactor meltdown at the two oldest reactors, the VVER 440/230, was 25 percent over the course of 23 years. These two reactors are currently 21 and 22 years old and are planned to continue in operation until 2003 and 2004.

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[39] In Moscow in September 1994, principal investigator Treadwell presented a paper at the Ministry for Civil Defense Affairs, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM) meeting. Conference members endorsed the idea of a monitoring network. Follow-up meetings with the Russian ministries of Foreign Affairs, HYDROMET, MINATOM, Emergency Response, and Environment, and U.S. DOE and the State Department took place. The result was a request for a more specific proposal for the installation of radionuclide monitoring systems (15).

[40] Y.G. Vishnevskiy, June 1992, quoted in "Fact Sheet: Bilibino Nuclear Heat and Electric Power Plant," communication from U.S. Senator T. Stevens' Office, June 1993.

Poor maintenance practices, as well as technical weaknesses due to reactor design, contribute to safety hazards at Kola. A Bellona Foundation inspection on September 14, 1992, revealed large cracks in the concrete halls of the reactor, lack of proper illumination, cables and wires in disarray, elevated levels of radiation, and insufficient supplies of fire extinguishing equipment. Video cameras monitoring reactor hall no.1 were out of operation in August 1993. According to a 1992 report of the Russian Ministry of Security, formerly the KGB (Committee for State Security), the operators at Kola do not recognize the importance of their work. The report sharply criticized both MINATOM and the Russian government for operational problems at the plant, including the lack of qualified instructors to teach employees safety precautions. Several operators in control room no.1 had never even participated in courses on ways to handle a crisis. Also, the report noted that reactor construction at Kola is a safety risk in itself and recommended shutting down the reactors as soon as possible.

According to the Norwegian government, which operates a monitoring station located on the border with Russia, the Kola plant nearly suffered a meltdown in February 1993 when backup power to cooling systems failed. Norway has claimed that Kola is "one of the four or five most dangerous plants in the world."[41]

In the fall of 1994, a commission of MINATOM spent a week checking the station and concluded that Kola was not ready to operate in winter conditions. Equipment stocks were insufficient, and there were few funds for procuring fuel. Only one reactor was operational (8). The plant has had considerable economic problems since its customers stopped paying for the electricity they receive. The Petshenga nickel and the Severo nickel smelting works were largely responsible for the 14.5 billion rubles (approximately $2.96 million according to exchange rates on April 1, 1995) in outstanding claims in 1993. Paying workers' wages and purchasing fuel nearly forced shutdown of the Kola plant at that time. A number of debtor enterprises recently got together and took out a credit of 30 billion rubles (approximately $6.12 million) to repay the debt in part (18,48). Three out of four Kola reactors were shut down in September 1994, due in large part to financial concerns (39).

However, reports on the status of safety at the plant vary. An IAEA commission that inspected the Kola, Balakovo, Novovoronezh, and Kalinin stations in late 1994 is said to have found that there was no breach of internationally accepted operational procedures, and it did not report serious nuclear safety problems (33).

Regarding waste management, cooling water is discharged into Imandra Lake via a 1-km-long canal, and contaminated water is stored in tanks onsite. Low- and intermediate-level waste is stored near the power plant, and there is a plant for solidifying this waste before storage. Some low-level waste is burned in an incinerator. Spent fuel assemblies are stored in water pools beside each reactor. They remain there for three years and are then sent to Mayak for reprocessing (48).

Kola, along with Sosnovy Bor, has been scheduled to receive a new generation of PWRs, the first of which is the VVER-640. Apparently, the local population on the Kola peninsula has given its approval to plans for a second plant, AES-2, which is to be built near the first plant, AES-1, on the shores of Lake Imandra. The first unit of the new facility, which will include three VVER-640 reactors, has been scheduled to start up when units 1 and 2 at AES-1 should be decommissioned. The other two units would come online later. The Kola-2 project is estimated to cost $3.5 billion–$4 billion, with Germany's Siemens Company helping to supply equipment.[42] AES-1, when all units are in opera-

[41] "Russia's Arctic Struggles with Nuclear Legacy," *AP Newswire*, Dec. 6, 1994.

[42] Siemens has entered into a joint venture with the Russian nuclear industry, forming the company Nuklearkontrol to produce automatic systems for controlling technological processes at nuclear power plants. Services will include development, delivery, and maintenance of automatic systems. Siemens also plans to produce computer software for automatic control systems.

tion, produces 60 percent of the region's electricity (16,34,38).

Other advances in plant safety are being made. An acoustic system to register leakages in the primary cooling circuit of the two oldest reactors is being installed (48). Negotiations are under way for the G-7 to contribute funds to the Nuclear Safety Account (NSA) administered by the EBRD for upgrades at Kola reactors 1 and 2 (VVER 440/230) (13). Norway has contributed $2.4 million to the NSA and has strongly emphasized that the Kola facility be given high priority. Experts from EBRD, Norway, and Finland visited Kola in November 1993 to lay the groundwork for a program there.

EBRD announced in late April 1995 that it would give $25 million to the Kola plant for safety improvements, including equipment for radiation control and fire risk minimization (14). Norway contributed $24 million in bilateral assistance to Kola in 1993 and 1994 to improve plant safety. This money helped to pay for a diesel generator for emergency power, wireless telephones, and training in safety routines. Norway is also providing assistance in the transfer of technology and expertise on conservation measures and alternative sources of energy, so that dependence on nuclear power decreases.

The Norwegian State Inspection for Radioactive Security is seeking cooperation with Russia in the inspection of the Kola and Sosnovy Bor power plants and has suggested investments in support of the radiation supervision bodies in Murmansk and at the Sosnovy Bor plant (50). Russia, Norway, and Finland scheduled five days of training exercises in May 1995 to coordinate actions in case of an accident on the Kola Peninsula. Rosenergoatom and the Ministry for Emergency Situations are in charge of the training exercises (56). Cooperation in the nuclear safety arena with Finland includes an arrangement to send daily status reports from the Kola plant to Finland (57).

DOE's projects specifically regarding the Kola plant include a plan to build a full-scope simulator. The scope of work for the simulator project had been agreed upon by March 1995, and specifications are in progress. Confinement system upgrades have been undertaken, including projects to provide confinement isolation valves and postaccident radiation monitors, and measures to ensure confinement leaktightness. Engineered safety system upgrades at Kola include a project to provide a reliable DC power supply for VVER 440/230 reactors 1 and 2 (66).

CONCLUSIONS

In the main, the Russian Federation has the responsibility of addressing the issues of prevention of future accidents or nuclear waste discharges associated with the nuclear fleets and power plants in the Arctic. The Russian government must also finance the decommissioning and dismantlement of a few hundred nuclear-powered submarines and ships, provide reprocessing facilities for the spent nuclear fuel from power plants and naval reactors, construct new liquid and solid waste treatment facilities, and upgrade the safety of shore-based nuclear plants to comply with international standards. Russia has made efforts to address these problems and has most of the required expertise but lacks funding or, in some cases, the safety and environmental protection culture to give these problems high priority.

Nuclear Fleet Decommissioning

The rapid retirement and decommissioning of first- and second-generation submarines of the nuclear fleet since the breakup of the former Soviet Union in 1991 has caused serious problems.

In recent years, only a small percentage of laid-up nuclear submarines have been decommissioned. Many of these submarines have not had their spent fuel removed from the reactor core. The condition of submarine reactor vessels is not well known outside Russian Navy circles. Northern Fleet submarines are docked along the fjords of the Kola Peninsula, near the cities of Murmansk and Severodvinsk. Pacific Fleet laid-up submarines are concentrated on the Kamchatka Peninsula and near the city of Vladivostok. Russian sources estimate that at the present rate, it will take decades to defuel and dismantle their decommissioned nuclear ships and submarines. The possibility of serious accidents will be greatly increased until these laid-up submarines, many of which have not been defueled, are fully decommissioned and secured.

As of late 1994, about 121 first- and second-generation nuclear submarines had been decommissioned; however, only about 38 of these have had their spent fuel removed from the reactor core. Presumably, the bulk of these submarine reactor plants have kept their main coolant loop systems running and continuously manned at dockside. After shutdown of the reactor, this is necessary to prevent heat buildup and accelerated corrosion of reactor fuel elements. Prior to defueling, each reactor must be monitored continuously to maintain proper water chemistry. The purpose is to minimize long-term corrosion of the fuel element containment vessel. The greatest risk of accidental explosion and release of radionuclides occurs during the defueling/refueling process. However, indefinite fuel storage in submarine reactors is risky. Besides the possibility of corrosion-related failures and subsequent leakage to the environment, the entire ship's hull must be treated as high-level nuclear waste until the spent fuel is removed. Failure to take timely action will result in the need to provide long-term storage for dozens of reactor compartments whose reactor cores are filled with spent fuel.

Four of these laid-up submarines have had serious accidents during the fuel removal process, including an incident at Chazhma Bay in the Far East, and will now require special handling to store the reactor cores safely. Safe dismantling and disposal of reactor compartments containing damaged fuel is much more difficult and costly than a plant with spent fuel removed.

Spent Fuel Management

Spent nuclear fuel management as practiced in Russia includes at least four stages: 1) defueling at shipyards and on service ships; 2) loading into transportation casks; 3) shipment by rail to the reprocessing facilities at Mayak in the Ural Mountains; and 4) reprocessing into fresh fuel elements. OTA's analysis indicates that there are massive bottlenecks in the management of spent nuclear fuel. The major problems presently associated with these stages are:

1. *Defueling and Storage:* The principal problems relate to the existing backlog of spent fuel, high rates of submarine deactivation, and lack or poor quality of fuel reloading and storage equipment (including land-based stores, service ships and refueling equipment, and spent fuel transfer bases). The continuing presence of spent fuel on deactivated submarines and poorly maintained floating storage facilities increases the possibility of an accident and complicates removal of the fuel in the future.
2. *Spent Fuel Shipments:* Removal of spent fuel from naval and icebreaker bases is impeded by the difficulties of transition to new TUK-18 shipping casks, installing new fuel transfer equipment, and upgrading local transportation links and other infrastructure.
3. *Nonstandard and Damaged Fuel:* Several technical issues relate to uranium-zirconium alloy and to damaged or failed fuels. Although the volume of such nonstandard fuels is not very large, its management and final disposition require additional research and technology development.
4. *Costs:* Because of the budget deficit and economic crisis, financing of spent fuel management operations is difficult. There are also institutional problems related to the question of which agency (MINATOM, Ministry of Defense, MSC, Goscomoboronprom) will pay for various stages of fuel management operations.
5. *Personnel and Social Problems:* The severe climate, the underdeveloped social and economic infrastructure of naval facilities and associated towns, relatively low salaries, and the decreasing social prestige of the military have resulted in the exodus of qualified personnel from the Navy and the shipbuilding industry. There is also a problem of training. It

was suggested that because of insufficient training the possibility of a serious accident due to human error (similar to the Chazhma Bay explosion)[43] may have increased over the past several years (26).

Recently, some progress has been made by Russia in identifying the choke points in its nuclear fuel cycle and taking corrective action, particularly in the Northern Fleet and at Murmansk Shipping Company. These efforts have benefited from a high level of international attention, assistance, and bilateral cooperative efforts with Russia's Scandinavian neighbors (particularly Norway), the European Union, and the United States. Nurturing and expansion of these efforts might achieve a significant reduction in risk of future accidents. Progress in fuel management in the Pacific Fleet has been far less encouraging to date. Although Japan has pledged $100 million to assist in waste management, very little has been achieved to date.

Liquid Low-Level Radioactive Waste

Liquid low-level radioactive waste (LLW) processing facilities are urgently required to relieve the overcrowded storage sites at naval facilities on the Kola Peninsula and in the Vladivostok area.

Until 1993, the (former) Soviet Union dumped liquid low-level waste generated from the operation and maintenance of its naval reactors into the ocean. Although facilities had been constructed by the Soviets for treatment of naval LRW, they were never put in operation. The dumped waste fluids included primary loop coolant from PWR cores, as well as decontamination solutions used in cleaning the primary loop.

The Murmansk Trilateral Initiative, which provides support to MSC to upgrade its LRW processing capabilities has recently been initiated. A design phase contract was signed in June 1995. Under the current plan, the next step is for the United States and Norway to each contribute $750,000, a total of $1.5 million for construction. This will be used to upgrade MSC's liquid LLW processing capacity to handle the liquid waste generated by MSC and the Northern Fleet. However, this is only a beginning, and no comprehensive plan for solving all of the related fuel handling and processing, transportation, or dismantlement problems has been developed. The Russians have demonstrated that they have the technology to solve their own problems; what is needed, however, is a framework for long-term planning, commitments regarding implementation of international standards, and reliable project financing.

Solid Radioactive Waste

Storage and handling of low-level solid radioactive waste (SRW) also requires attention, particularly with respect to long-term management of the problems on a regional basis. The dismantlement of nuclear submarine hulls and sealing of reactor compartments for long-term storage is proceeding at a very slow pace. As of the end of 1994, only 15 decommissioned nuclear submarines had been completely dismantled. Although Russian shipyards have the capacity and technology required to handle this problem, dismantlement has not been adequately funded. It is not clear how the Russian government will provide the funds needed for safe and comprehensive dismantlement in the future.

If submarine dismantlement continues as planned, permanent storage for low- and intermediate-level nuclear waste, including reactor compartments, will require at least one and possibly two regional facilities. Long-term storage facilities for reactor compartments, which are now stored in open water near Russian naval facilities, will be necessary.

[43] On Aug. 10, 1985, an Echo-II SSGN reactor exploded during a refueling operation at the Chazhma Bay repair and refueling facility. The explosion resulted from inadvertent removal of control rods from the reactor core.

Civilian Nuclear Reactor Safety

Russian nuclear reactor safety is a major concern of the international community. The widespread contamination resulting from the Chernobyl Nuclear Power Plant accident in 1986 has precipitated major international interest in the safety of nuclear reactors operating in the fSU. Much of the international support is focused on the prevention of potential accidents in the future. Western experts have concluded that the Russian plants need modernization or replacement to achieve parity with the West. However, based on current Russian government plans, it will be approximately a decade before a significant number of the oldest reactors are replaced with upgraded units. The rate of replacement will be influenced heavily by the pace of recovery of the overall Russian economy.

Reactor accidents at several nuclear powerplant sites would potentially be direct threats to the Arctic environment. Two old-generation VVER-type pressurized water reactors are located on the Kola Peninsula in Murmansk Oblast. The Kola plant provides two-thirds of the electrical power to Murmansk Oblast. While these two older plants are still operating, newer plants incorporate more international safety standards and operating procedures. Norway, which closely monitors operations at Kola from its nearby border, claims that these reactor units constitute "one of the four or five most dangerous plants in the world."[44]

Bilibino, a small-capacity reactor site with four 11-MW, EPG-6 boiling-water-type, units is also located within the Arctic Circle in the Siberian Far East. Although the Bilibino reactors are graphite moderated, boiling water cooled, and similar in design to the much larger Chernobyl RBMK units, they present less of a safety risk, due mainly to the remote location and the small size of the plants.

International action focused on building a safety culture in Russian civilian nuclear programs has had mixed results to date. The most significant international assistance has come through the European Union and the G-7. The G-7 summit conducted in Munich in 1992 produced an emergency action plan for enhancing the safety of Soviet reactor designs. G-7 countries have pledged funding totaling more than $1 billion.

Norway and the United States are significant bilateral contributors to programs addressing radioactive contamination and reactor safety in the fSU. Early in 1995, the Norwegian government created an action plan to address the remediation of dumped nuclear waste, the operational safety of reactors, and the hazards of weapons-related activities. The United States has funded programs administered by DOE and NRC. The bulk of this funding has been directed toward implementing technical fixes, operational improvements, and installing regulatory procedures at fSU reactor sites. Many experts argue that programs should be directed toward longer-term initiatives, such as ensuring adequate Russian cash flow to operate the plants, as well as establishing sound institutional and management underpinning for nuclear powerplant operations.

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